Corrosion

NOVEMBER, 1958

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TECHNICAL SECTION

CONTENTS

THIS MONTH'S COVER—These are some of the largest fasteners ever made of Hastelloy alloy C for chemical industry service. The hand touches a 1½ inch machine bolt. Among the pieces in the order were bolts almost three feet long.

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SCHEDULED FOR PUBLICATION IN DECEMBER

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Corrosion Properties of Ta, Cb, Mo and W by Clifford A. Hampel

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Chloride Stress Corrosion Cracking of Austenitic Stainless Steel—Effect of Temperature and pH by L. R. Scharfstein and W. F. Brindley

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Corrosion of Refinery Equipment During Acid Cleaning by K. R. Walston and A. Dravnieks

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Four Case Histories: Intergranular Corrosion of Austenitic Stainless Steel in Petroleum Refineries by J. R. Cunningham

Engineering Colleges vs Corrosion by Richard V. James

☆

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more 13, Maryland

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5, D. C.

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Topic of the Month

Elimination of a Tank Vent Line Corrosion Problem Through the Use of Aluminum Pipe and Fittings

*By R. E. BROOKS**

Introduction

CRUDE PETROLEUM from a producing oil field is stored in lease stock tanks prior to delivery to a pipeline company. The crude oil, although passing through a gas-oil separator and/or emulsion treater, still contains appreciable quantities of hydrocarbon gas. In addition the produced gas may contain large volumes of hydrogen sulfide and carbon dioxide gases.

When the produced crude oil containing both free and solution gases enters the lease storage facility, it is still under line temperature and pressure. The agitation of the oil as it enters the stock tank, coupled with the reduction in pressure within the tank, results in release of gases which rise into the vapor space of the stock tank. When the stock tank oil is withdrawn near the tank bottom, a partial vacuum results in the vapor space of the tank and considerable quantities of oxygen are drawn through the tank vent lines into the tank vapor space. The resultant mixture of oxygen-rich hydrocarbon, hydrogen sulfide, and carbon dioxide gases is, in the presence of moisture, extremely corrosive toward steel tank decks and venting facilities.

The Big Horn Basin of North Central Wyoming contains numerous oil fields which produce sour crude oil and/or sour gas. The produced gases, as well as being extremely corrosive toward lease equipment, are toxic and present a hazard to field personnel who must enter lease storage facilities. Consequently, many operators in the area have abandoned the use of single stacks from individual tanks and have used, instead, closed vent lines feeding into a common stack. Thus, the corrosion problem associated with the closed venting systems is identical to that in the stock tank vapor space.

Since aluminum tank decks have proven excellent in negating vapor space corrosion in lease stock tanks, it was felt that light walled aluminum pipe would prove an excellent material for fabrication of tank vent lines. The nature of the application was such that laboratory studies were not applicable;

therefore, it was decided that this evaluation of aluminum pipe would be carried out under operating service conditions.

Field Tests

The site selected for field testing was in a sour field in Wyoming's Big Horn Basin. At the test location, a venting system of light wall steel pipe was used to vent gas from four low 500 bbl and two high 1000 bbl bolted steel tanks. The steel venting system suffered such severe internal corrosion that the lines were removed at least twice yearly for repair in the welding shop. The exterior surfaces of the lines were also severely attacked and required additional expensive maintenance.

On October 13, 1955, the existing venting system at the test site was replaced with an aluminum venting system composed of 4-inch x 0.072-inch aluminum pipe in alloys 5086 and Alclad (7072)5086. The pipe was cut to length at the location and was joined by a union-type flared connection. Mitered 90 degree aluminum elbows and tees, fabricated in advance at the laboratory, were used where required. Additionally, to connect the vent lines to the 3-inch hillside tank flanges, schedule 40 steel 4-inch to 3-inch swedges were cut to length, 4-inch OD x 14 gauge steel boiler tube was welded into the swedges, an aluminum connection was slipped

over the boiler tube, and the steel tube was flared to a 45 degree angle. To prevent corrosion of the steel parts, all internal steel surfaces in the venting system were coated with a neoprene base paint (Figure 1).

The aluminum test lines shown in Figure 2 have been unaffected by corrosion after three years' service. The lines were inspected in July 1957 and no attack was noted in either the bare 5086 or Alclad(7072)5086. The plastic coating in the steel connections has sloughed locally from the coated fittings, and some attack of the steel has been observed. The use of coated steel in this application was one of expedience and in future installations only cast aluminum fittings will be used.

Based on the fact that no corrosion of the aluminum material has occurred after three years, it is anticipated that in this service aluminum pipe and fittings will have a minimum life of 15 years without repair or maintenance. This prediction is supported by the excellent performance of aluminum tank decks which have been in continuous use in this area for approximately 15 years.
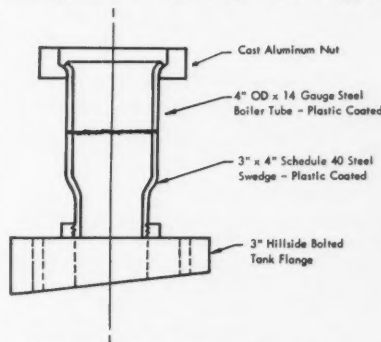
Figure 1—Assembly utilized to connect aluminum vent lines into the hillside tank flanges. To prevent corrosion of the steel components, the assembly was internally coated with a neoprene base paint.

Labels in figure:
Cast Aluminum Nut
4" OD x 14 Gauge Steel Boiler Tube – Plastic Coated
3" x 4" Schedule 40 Steel Swedge – Plastic Coated
3" Hillside Bolted Tank Flange
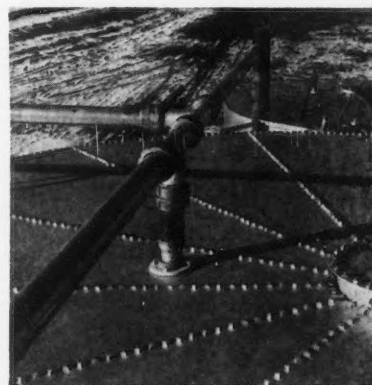
Figure 2—View of aluminum venting system taken from the top of a 1000-bbl tank. Shop fabricated 90 degree ells and tees were used in this installation. The line at the left runs into a common stack consisting of a 30-foot length of aluminum pipe with a base plate attached.

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The Electrochemical Behavior of Aluminum*

Potential pH Diagram of the System Al-H₂O at 25 C

By E. DELTOMBE[1] and M. POURBAIX[1]

1. Introduction

THIS ARTICLE describes the application to aluminum of a method established by Pourbaix[1] for the study of the electrochemical behavior of metals and metalloids in the presence of aqueous solutions. It is one of a series of articles prepared in connection with a work to be entitled "Atlas of Electrochemical Equilibria." This series is composed of two groups of articles. One group discusses the general method of study;[1,2,3] the other group consists of articles on the following substances: water,[1] chromium,[1,4] hydrogen peroxide,[8] cobalt,[4,5] copper,[1] cyanides,[4,5] iron,[1,4,5] germanium,[4] lead,[5] magnesium,[4] molybdenum,[4] nickel,[4] nitrogen,[1] silver,[8] tellurium,[4] tin,[4,5] titanium,[4,5] tungsten,[4] and zinc.[5]*

Similar reports have been made for chlorine (Valensi),[6] iodine (Brown),[7] sulfur (Valensi),[8] and zirconium (Maraghini and Van Rysselberghe).[9]

A preliminary work on aluminum was published in 1951 by Delahay, Pourbaix, and P. Van Rysselberghe.[10] Patrie[11] in 1951 used the same method for the study of layers of oxide on aluminum in nitric acid. In 1953 this method was applied to the study of the corrosion of aluminum by Groot and Peekema,[12] who drew a corrosion diagram for a concentration of dissolved aluminum equal to 3×10^{-6} gram atomic weights/liter.

The object of the present work is to set forth the electrochemical behavior of aluminum according to the standard form established for the "Atlas of Electrochemical Equilibria." It is a comprehensive study based on the most reliable published data. The first step is to establish on the basis of the original data in the literature, the values for the standard free energies of formation of the constituents of the system Al-H₂O at 25 C. A table is then given of the reactions in which the constituents are able to participate, and an equilibrium potential-pH diagram derived. With this diagram, an interpretation is made of the stability of aluminum and its oxides.

2. Standard Free Energies of Formation at 25 C

Values accepted for the standard free energies of formation at 25 C are listed

below. The values not marked by the sign (°) are those indicated by Latimer.[13] All the values are expressed in small calories. In the case where the reference does not indicate significant figures for the hundreds, tens, and units of small calories, the zero has been used. To permit the reader to appreciate the degree of precision which may be attributed to these values, the digits which may be reasonably considered as exact have been underlined; however, the last digit in each series is to be used with caution.

Dissolved Substances

H₂O	— 56,690 cal
H⁺	0
OH⁻	— 37,595
Al⁺⁺⁺	—155,000
(°) AlO₂⁻	—200,710
(°) H₂AlO₃⁻	—257,400

Solid Phases

Al	0 cal
Al(OH)₃ amorphous	—271,900
a. Al₂O₃ (corundum)	—376,770
b. Al₂O₃·H₂O (böhmite)	—435,000
(°) c. Al₂O₃·3H₂O (bayerite)	—552,470
(°) d. Al₂O₃·3H₂O (hydrargillite)	—554,600

Here is how the values for the compounds of aluminum have been established:

Al^{+++} (—115,000 cal.) Latimer adopted the value given by the Bureau of Standards. This value is based on the heat of formation (—125,400 cal) and the entropy (—70.9 cal/°C determined by Latimer and Greensfelder.[14]

$Al(OH)_3$ (—271,900 cal.) Latimer based this value on the heat of formation (—304,000 cal) and the entropy, estimated at 17 cal/°C. It corresponds to $\mu°Al_2O_3 = -(2 \times 171,900) + (3 \times 56,690) = -372,730$ cal.*

αAl_2O_3, corundum (—376,770 cal). Latimer adopted the Bureau of Standards value calculated from the heat of formation (—399,090 cal) and the entropy (12.186 cal/°C).

$Al_2O_3·H_2O$, bohmite (—435,000 cal). Latimer adopted the Bureau of Standards value calculated from the heat of formation (471,000 cal) and the entropy (23.15 cal/°C). It corresponds to $\mu°Al_2O_3 = -435,000 + 56,690 = -378,310$ cal.

(°) AlO_2^- (—200,710 cal) or $H_2AlO_3^-$ (—257,400 cal). Fricke and Meyring,[15] studying the aging of aluminum hydrox-

* $\mu°$ of Pourbaix and Deltombe corresponds to $\Delta F°$ of Latimer.

Abstract

A study was made of electrochemical behavior of aluminum in the presence of aqueous solutions. The potential-pH equilibrium diagram of the system aluminum-water at 25 C was developed from the standard free energies of the constituents, and the general electrochemical behavior of aluminum was deduced from the diagram. The diagram was established by considering the ions Al⁺⁺⁺ and AlO₂⁻ and the solid phases Al and Al₂O₃·3 H₂O (hydrargillite).

The diagram indicates the theoretical circumstances in which aluminum should show corrosion, immunity, and passivity, under the hypothesis that the passivation results from the formation of a film oxide whose stability resembles that of hydrargillite. The stability of aluminum and the different forms of its oxides are discussed. Curves are given of the solubilities of the oxides and hydroxides as functions of pH.   **3.6.5**

ide gels in solutions of caustic soda, stated that the first phase of the evolution of the gel is the formation of böhmite, Al₂O₃·H₂O. From pH measurements, they calculated for this compound the solubility product $(AlO_2^-) (H^+) = 6 \times 10^{-13}$ or $10^{-12.32}$. For the reaction $Al_2O_3·H_2O = 2 AlO_2^- + 2H^+$ the equilibrium relation may be written as log $K = 2 \log (AlO_2^-) + 2 \log (H^+)$. The general equilibrium relation is log K =

$$-\frac{\Sigma \nu \mu°}{1363} \text{ or } \log K = -\frac{\Delta F°}{2.303RT}$$

therefore $(—12.32) \cdot 2 =$

$$\frac{2\mu°_{AlO_2^-} + 2\mu°_{H^+} - \mu°_{Al_2O_3·H_2O}}{1363}$$

$$= \frac{2\mu°_{AlO_2^-} + 435,000}{1363}$$

from which it follows that $\mu°AlO_2 = -200,710$ cal. Writing the aluminate $H_2AlO_3^-$ $(AlO_2^- + H_2O)$ in place of AlO_2^- gives $\mu°_{H_2AlO_3} = -200,170 - 56,690 = -257,400$ cal. Latimer has calculated $\mu°_{AlO_2,} = -204,700$ cal, on the basis of an uncertain heat of formation (—218.6 cal) and an estimated entropy of 25 cal/°C. On the other hand, he has calculated $\mu°_{H_2AlO_3} = -255,200$ cal based on $\mu° Al(OH)_3 = -271,900$ cal and the solubility product $(H_2AlO_3^-) (H^+) = 4 \times 10^{-13}$ or $10^{-12.4}$ determined by Kolthoff.[16] This value of the solubility product agrees well with that calculated by Fricke and Meyring for böhmite; it is very probable that it likewise refers to böhmite and not to Al(OH)₃ as set forth by Latimer.

(°) $Al_2O_3·3H_2O$ bayerite (—552,470 cal). For the second stage of the aging of aluminum hydroxide gels in solutions of caustic soda, Fricke and Meyring

have characterized the formation of bayerite ($Al_2O_3 \cdot 3H_2O$) with a solubility product $(AlO_2^-)(H^+) = 1.5 \times 10^{-14}$ or $10^{-13.82}$. By applying the general equilibrium relation to the reaction $Al_2O_3 \cdot 3H_2O = 2AlO_2^- + 2H^+ + 2H_2O$, one obtains

$$(-13.82) \cdot 2 =$$
$$\frac{-2\mu°_{AlO_2^-} + 2\mu°_{H^+} + 2\mu°_{H_2O} - \mu°_{Al_2O_3 \cdot 3H_2O}}{1363}$$
$$= \frac{-401,420 - 113,380 - \mu°_{Al_2O_3 \cdot 3H_2O}}{1363}$$

From this it follows that $\mu°_{Al_2O_3 \cdot 3H_2O} = -552,470$ which correponds to $\mu°_{Al_2O_3} = -382,400$ cal.

($°$)$Al_2O_3 \cdot 3H_2O$, hydrargillite ($-554,600$ cal). The last stage of aging of the aluminum hydroxide gel in caustic soda corresponds, according to Fricke and Meyring, to the formation of hydrargillite $Al_2O_3 \cdot 3H_2O$, of which Fricke and Jucaitis[17] have calculated the solubility product $(AlO_2^-)(H^+) = 2.5 \times 10^{-15}$ or $10^{-14.60}$. By applying the general equilibrium relation to the reaction $Al_2O_3 \cdot 3H_2O = 2AlO_2^- + 2H^+ + 2H_2O$, one obtains

$$(-14.60) \cdot 2 =$$
$$\frac{-2\mu°_{AlO_2^-} + 2\mu°_{H^+} + 2\mu°_{H_2O} - \mu°_{Al_2O_3 \cdot 3H_2O}}{1363}$$
$$= \frac{-401,420 - 133,800 - \mu°_{Al_2O_3 \cdot 3H_2O}}{1363}$$

Hence, $\mu°_{Al_2O_3 \cdot 3H_2O} = -554,600$ cal, which corresponds to $\mu°_{Al_2O_3} = -384,530$ cal. Latimer had adopted the value of the Bureau of Standards, $-547,900$ cal, calculated from the heat of formation, $-613,700$ cal, and the entropy 33.51 cal/°C. This value, which corresponds to $\mu°_{Al_2O_3} = -377,830$ cal, would signify that hydrargillite is less stable than böhmite ($\mu°_{Al_2O_3} = -378,310$ cal) which is contrary to reality.

For want of thermodynamic data, it has not been possible to take into account the monovalent ions Al^+. These ions, in the opinion of many authors, notably Epelboin, are able to form during the anodic polarization of aluminum. For the same reason, it has not been possible to take into account the varieties of anhydrous alumina other than corundum α(rhombohedral). Such aluminas include β(hexagonal), γ(cubic), and δ (rhombohedral) aluminas.

3. Equilibrium Reactions and Formulas*

Homogeneous reactions, without oxidation
1. $Al^{+++} + 2H_2O = AlO_2^- + 4H^+$
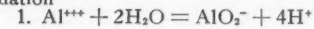
$$\log \frac{(Al^{+++})}{(AlO_2^-)} = 20.30 - 4 \, pH$$

Heterogeneous reactions involving two solid phases, with oxidation

2. $Al + 3H_2O = Al(OH)_3 + 3H^+ + 3e^-$
   $E = -1.471 - 0.0591 \, pH$
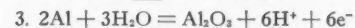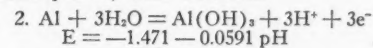
3. $2Al + 3H_2O = Al_2O_3 + 6H^+ + 6e^-$
   a. $E = -1.494 - 0.0591 \, pH$
   b. $\quad -1.505$
   c. $\quad -1.535$
   d. $\quad -1.550$

Heterogeneous reactions involving one solid phase, without oxidation

* In the formulas which follow the letters a., b., c., and d., are values for different oxides of hydrates of aluminum. The respective free energies of these compounds are given on page 16 under the heading "Solid Phases."
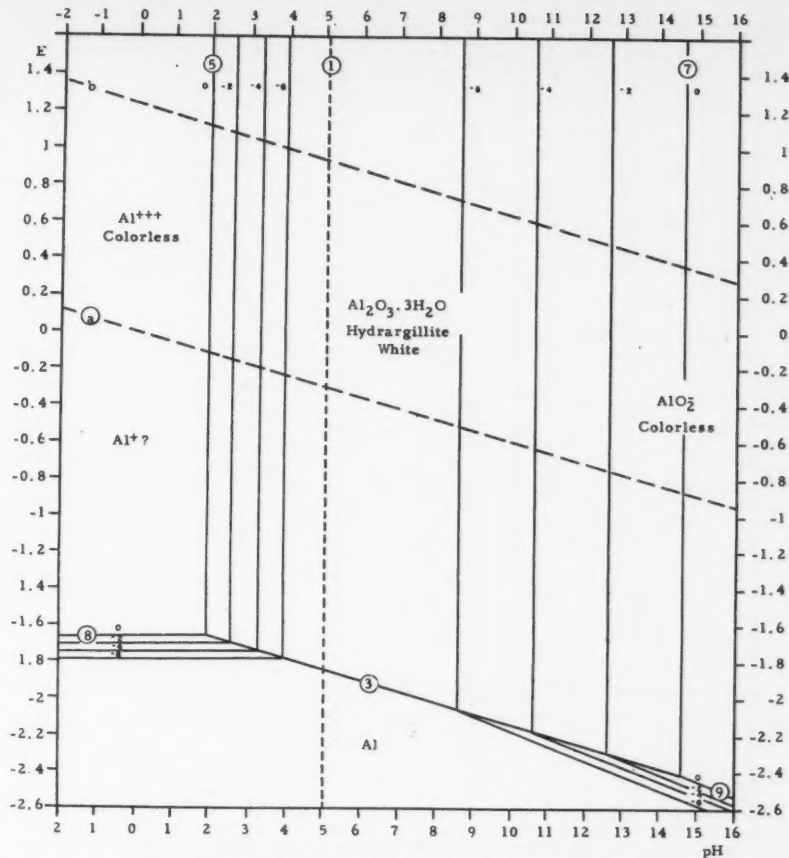
Figure 1—Potential-pH diagram for the system aluminum–water at 25 C.

4. $Al^{+++} + 3H_2O = Al(OH)_3 + 3H^+$
   $\log (Al^{+++}) = 9.66 - 3 \, pH$
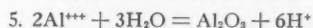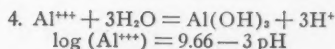
5. $2Al^{+++} + 3H_2O = Al_2O_3 + 6H^+$
   a. $\log (Al^{+++}) = 8.55 - 3 \, pH$
   b. $\quad = \overline{7.98}$
   c. $\quad = \overline{6.48}$
   d. $\quad = \overline{5.70}$

6. $Al(OH)_3 = AlO_2^- + H_2O + H^+$
   $\log (AlO_2^-) = \overline{-10.64} + pH$
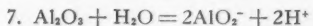
7. $Al_2O_3 + H_2O = 2AlO_2^- + 2H^+$
   a. $\log (AlO_2^-) = \overline{-11.76} + pH$
   b. $\quad = \overline{-12.32}$
   c. $\quad = \overline{-13.82}$
   d. $\quad = \overline{-14.60}$

With oxidation

8. $Al = Al^{+++} + 3e^-$
   $E = \overline{1.663} + 0.0197 \log (Al^{+++})$
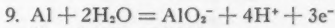
9. $Al + 2H_2O = AlO_2^- + 4H^+ + 3e^-$
   $E = \overline{1.262} - 0.0788$
   $\quad\quad + 0.0197 \log (AlO_2^-)$

4. Potential pH Equilibrium Diagram and Interpretation

A. Establishing the Diagram

On the basis of the equilibrium relations established in Part 3, one can draw, as in Figure 1, the equilibrium potential-pH diagram for the following dissolved bodies:

The colorless aluminum cation Al^{+++}
The colorless aluminate anion AlO_2^-

One does not take into account the cations $Al(OH)^{++}$ and $Al(OH)_2^+$; these do not seem to be as real as the chloride complexes. It is understood that the aluminate AlO_2^- could be represented equally well by the formula $H_2AlO_3^-$. Concerning solid phases, other than aluminum metal, a choice must be made between the several oxides and hydrates for which equilibrium formulas have been calculated. From the free energies established in Part 2, and reducing each to the anhydrous oxide Al_2O_3,** one is able to classify these oxides or hydrates as follows, in the order of decreasing free energy or increasing stability:

	cal
$Al(OH)_3$ amorphous $\mu° \, Al_2O_3 =$	$-373,730$
Al_2O_3 corundum $\quad\quad =$	$-376,770$
Al_2O_3 böhmite $\quad\quad =$	$-378,310$
$Al_2O_3 \cdot 3H_2O$ bayerite $\quad =$	$-382,400$
$Al_2O_3 \cdot 3H_2O$ hydrargillite $=$	$-384,530$

Hydrargillite, $Al_2O_3 \cdot 3H_2O$, which is shown in the table as the most stable hydrated alumina, has been chosen for drawing the equilibrium diagram. Figure 1 represents the thermodynamic

** The free energies are deduced from the conditions of equilibrium for the reactions:

$$2Al(OH)_3 = Al_2O_3 + 3H_2O \text{ or}$$
$$2\mu°_{Al(OH)_3} = \mu°_{Al_2O_3} + 3\mu°_{H_2O}$$

$$Al_2O_3 \cdot H_2O = Al_2O_3 + H_2O \text{ or}$$
$$\mu°_{Al_2O_3 \cdot H_2O} = \mu°_{Al_2O_3} + \mu°_{H_2O}$$

$$Al_2O_3 \cdot 3H_2O = Al_2O_3 + 3H_2O \text{ or}$$
$$\mu°_{Al_2O_3 \cdot 3H_2O} = \mu°_{Al_2O_3} + 3\mu°_{H_2O}$$
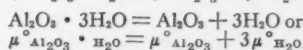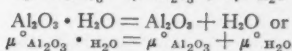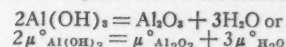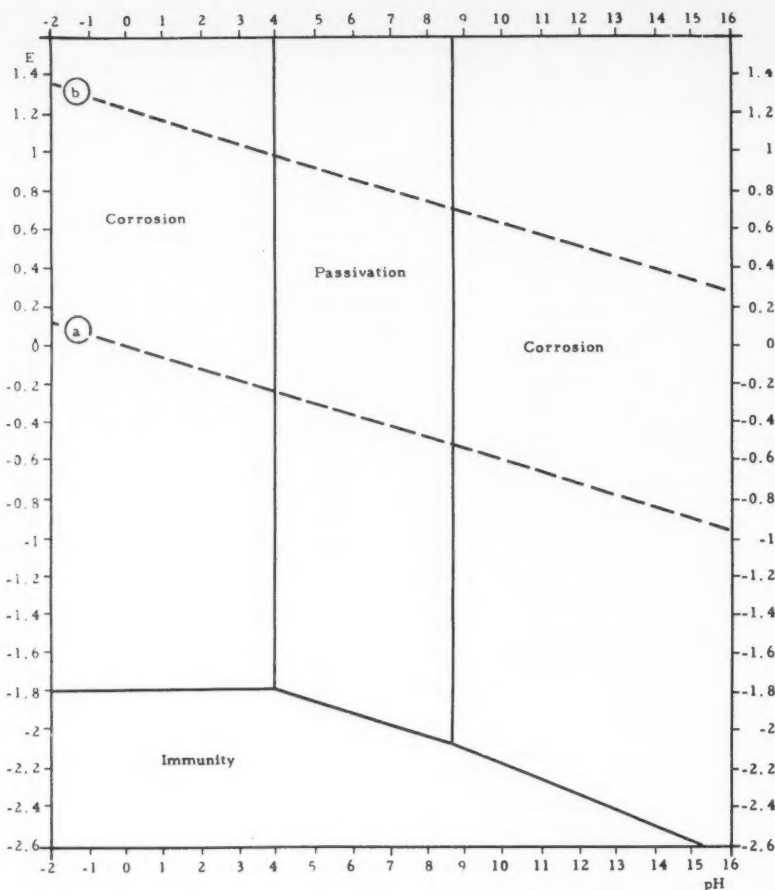
Figure 2—The corrosion, immunity, and passivation of aluminum at 25 C. Findings were based on passivation by a film of hydrargillite, Al₂O₃ • 3 H₂O; figure was deduced from Figure 1.

a. log V as a function of pH   b. V as a function of pH

V = rate of corrosion in mg. /dm² hr.
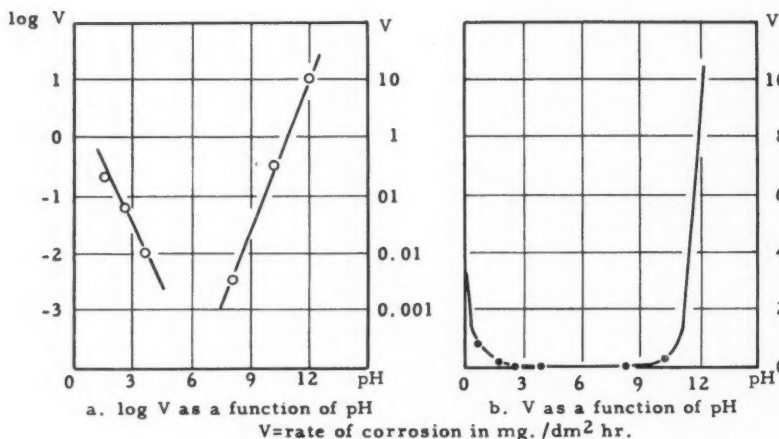
Figure 3—Influence of pH on the rate of corrosion of aluminum (Shatalov).

equilibrium of the system Al-H₂O at 25 C in the absence of complexing substances and substances forming insoluble salts. It is reported that the complexes of aluminum are numerous. The most important are those produced by organic anions—citrate, tartrate, oxalate, etc. as well as the fluoride complexes (Charlot).[18] Slightly soluble compounds are the phosphate and the oxinate. Calcium aluminate also is only slightly soluble.

B. Stability and Corrosion of Aluminum

According to Figure 1, aluminum is a very base metal, in that its domain of stability is far below that of water. In the presence of water, it tends strongly to decompose water with evolution of hydrogen, dissolving to form the ion Al⁺⁺⁺. Under certain conditions so far poorly elucidated, the dissolution may occur with formation of the monovalent ion Al⁺. In the presence of alkaline solutions also, aluminum has a strong tendency to decompose water with evolution of hydrogen, dissolving to form the aluminate ion AlO₂⁻.

In solutions which do not complex aluminum ion, aluminum tends to be covered with a protective film of oxide. The exact nature of this oxide is not understood nor are its thermodynamic characteristics. Thus Figure 1 has been drawn on the basis that the protective film is hydrargillite Al₂O₃ • 3 H₂O, or an Al₂O₃ of equivalent free energy formation ($\mu°_{Al_2O_3} = -384{,}530$ cal).

Under these conditions, in a non-complexing solution, the covering of the metal with a layer of oxide is produced from pH = 2 to pH = 14.6 in solutions one molar in dissolved aluminum, and from pH 4 to pH 8.6 in solutions 10⁻⁶ molar. It is probable that the oxide which forms has a free energy even smaller than that which corresponds to hydrargillite, and, consequently, the solubility is even smaller. Figure 2, deduced from Figure 1, represents, under certain hypotheses[2] the theoretical circumstances of corrosion, immunity, and passivation of aluminum in a solution free of substances which are able to form soluble complexes or insoluble salts of this metal.

In practice, the corrosion behavior of aluminum is determined by the behavior of the film of oxide (with which it is nearly always covered) toward the solutions concerned. The cases of poor corrosion resistance of aluminum often are connected with the development of this film of oxide, notably with its degree of hydration. In general, it is observed that the dissolution of the film is slower in acids than in alkaline solutions. If the film of oxide is eliminated, the attack is immediate, both in acid and in alkaline solutions. Water is in general without action except in particular cases when there is danger of pitting. Shatalov[19] has studied the rate of corrosion as a function of pH in various solutions and expressed the results in a semi-logarithmic graph which has been reproduced in Figure 3a. In Figure 3b, these same results have been transferred to a graph with linear co-ordinates, which emphasizes the slow rate of corrosion between pH 4 and pH 8, and the rapid increase outside these limits.

The equilibrium electrode potential is practically impossible to measure directly, because of the great probability of evolution of hydrogen at low potentials. In addition, the measurements are complicated by the strong tendency of the aluminum to cover itself with a nonconductive layer of oxide. The results obtained are always higher than the values calculated theoretically. Among the number of tentative values for the potential of this electrode are those of Heyrovsky,[20] who used a liquid amalgam of aluminum. The mercury in the amalgam eliminated the evolution of hydrogen by increasing the hydrogen overvoltage. Heyrovsky has stated that under these conditions the secondary reaction H₂ = 2H⁺ + 2e⁻ is practically eliminated. The observed potential, however, does not correspond to the reaction Al = Al⁺⁺⁺ + 3e⁻ but rather to the reaction Al + 3OH⁻ = Al(OH)₃ + 3e⁻

The anodic behavior of aluminum is also affected by the formation of a pas-

sive layer of oxide on the surface of the metal. However, when conditions are the least favorable to the formation of the film, one can obtain anodic dissolution in the most diverse solution, acid and alkaline, with a current efficiency equal to or even greater than 100 percent. This value is calculated from the formation of the trivalent aluminum ion Al^{+++}. An efficiency of more than 100 percent implies the formation of ions of aluminum of valence less than three, as, for example Al^+. Thus, according to Gunther-Schultz,[21] the efficiency is practically 100 percent in HNO_3, and according to Blum and Rawdon,[22] it is above 100 percent for rotating anodes in 1M HCl, 1M CH_3CO_2H, 1M NaOH, and 1M NH_4OH; in the solutions of salts, the dissolution of aluminum is always accompanied by the formation of a precipitate of $Al(OH)_3$. Much use is made of anodized aluminum. Anodizing covers the aluminum with an oxide film which imparts desirable properties, such as the absorption of colored materials and resistance to chemical agents and to the passage of electric current. According to Patrie,[23] this layer consists essentially of a very thin layer of anhydrous α alumina directly in contact with the metal, while the part in contact with the bath is made of alumina monohydrate, $Al_2O_3 \cdot H_2O$, produced by the action of the water on the layer of Al_2O_3.

The cathodic protection of aluminum is practically impossible because of the very low value of the potential of protection (—1.78 volt). For the same reason, the electrodeposition of aluminum from aqueous solution is practically impossible. Many attempts have been made but without practical success, though under very special conditions one can deposit the metal. The classic procedure of electrowinning the metal is based on the electrolysis of its molten salts.

C. Stability of the Oxide of Aluminum and Its Hydrates

The oxide of aluminum, or alumina (Al_2O_3) occurs in diverse forms. The ordinary variety is corundum, called α alumina, crystallizing in the rhombohedral class. The others are β alumina with hexagonal crystals, γ alumina with cubic crystals, and δ alumina with rhombohedral crystals. The physical and chemical properties of aluminas are dependent in large measure on the temperatures attained in their preparations. When heated to high temperatures, aluminas lose their hygroscopic properties and become practically insoluble in acids or bases.

When alkali is added to a solution of an aluminum salt, or acid to a solution of an aluminate, one obtains a precipitate, hydroxide gel, corresponding essentially to the composition $Al(OH)_3$ and amphoteric in nature. However, the aluminum hydroxide gel is not stable. It crystallizes eventually to give the monohydrate of böhmite, crystallizing in the rhombohedral system. It then gives the trihydrate or bayerite, crystallizing in the monoclinic system, and finally another trihydrate, hydrargillite, crystallizing in the same system. This evolution of the hydroxide of aluminum is known as "aging." The diverse hydrates formed in the course of aging are characterized by greater and greater stabilities, and concomitant variation in all their properties, particularly in their
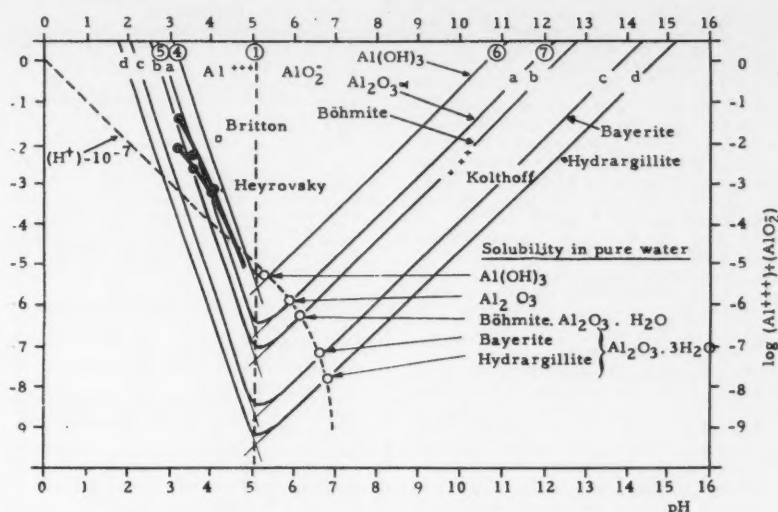
Figure 4—Influence of pH on the solubility of Al_2O_3 and its hydrates at 25 C.

TABLE 1

	Al_2O_3 (cal)	log (Al^{+++}) (OH^-)	log (AlO_2^-) (H^+)	log (min. sol.) gm. at Al/1. at pH 5.1	log (sol. in water) gm. at Al/1
Al(OH)₃	—373,730	—32.34	—10.64	—5.3	—5.3 (pH = 5.3)
Al₂O₃	—376,770	—33.45	—11.76	—6.4	—5.9 (pH = 5.9)
Böhmite	—378,310	—34.02	—12.32	—7.0	—6.2 (pH = 6.1)
Bayerite	—382,400	—35.52	—13.82	—8.5	—7.2 (pH = 6.7)
Hydrargillite	—384,530	—36.30	—14.60	—9.2	—7.8 (pH = 6.8)

solubilities in acids, bases, and pure water.

In Figure 4 a series of curves have been drawn showing the influence of pH on the solubilities of the several compounds for which the values of the free energy are available. The curves result from the equilibrium relations of Part 2. Information given for each of the compounds includes the value of the free energy reduced to Al_2O_3, the logarithm of the solubility products in acids and bases, the logarithm of the minimum solubility at pH 5.1, and the solubilities in pure water. All these data were deduced from the equilibrium relations of Part 2, on the curves of Figure 4. Among these data, those relative to the alkaline solubility of böhmite ($10^{-12.32}$), of bayerite ($10^{-13.82}$), and of hydrargillite ($10^{-14.60}$) are necessarily equal to the values shown by Fricke and Meyring[15] and by Fricke and Jucaitis,[17] for these were the values that served as the basis for the calculations of the free energies of these compounds (see Part 2). As likewise indicated in Part 2, Kolthoff[16] measured a solubility product of $10^{-12.4}$, which Latimer considered to be that of the hydroxide $Al(OH)_3$. It appears that this value is much closer to that of böhmite than to that of $Al(OH)_3$. It is thus probable that Kolthoff allowed his hydroxides to stabilize so that at the moment of measurement they were not $Al(OH)_3$. The three points corresponding to the measurements of Kolthoff are shown in Figure 4.

The solubility product in acid solutions is more difficult to determine because of the mixture of ions that may occur. This $AlCl_3$ in solution exists in the three forms, Al^{+++}, $AlCl^{++}$, and $AlCl_2^+$, which upon hydrolysis give respectively

$Al(OH)_3$, $AlCl(OH)_2$, and $AlCl_2OH$. Heyrovsky[24] has made a calculation of the solubility product (Al^{+++}) (OH^-)$^{-3}$ based on measurements of conductivities and electromotive forces in concentration cells of aluminum chloride, and has obtained in that way the value 1.06×10^{-33} (or $10^{-32.97}$) for very dilute solutions. According to Table 1 this value is intermediate between those calculated for $Al(OH)_3$ and for Al_2O_3. In Figure 4, a curve has been drawn corresponding to Heyrovsky's solubility product of $10^{-32.97}$ for concentrations of less than 10^{-4} M. For higher concentrations, the upper and lower limits given by that author for the value of Al^{+++} have been represented as a function of pH.

Britton,[25] studying the variation with pH of the course of precipitation of a solution 0.00667 M in $Al_2(SO_4)_3$ (or $10^{-1.88}$ M in Al) by caustic soda, has observed that a precipitate began to separate for that solution at pH 4.14. This is certainly a case of freshly precipitated $Al(OH)_3$, and the point expressing the result of Britton is in Figure 4.

Experimental data on the minimum solubilities of the hydrates of alumina are almost non-existent. However, Edwards and Burwell[26] stated that, in the practice of service water clarification by compounds of aluminum, one rarely observed a residual concentration of aluminum in the treated water above 2 mg Al/1, or $10^{-4.1}$ gm. at. Al/1. According to laboratory tests the minimum solubility of $Al(OH)_3$ lies between pH 5.5 and 7.8.

Concerning solubilities in pure water, Remy and Kuhlman[27] have calculated that of Al_2O_3 at 20 C by conductometric titration (0.92×10^{-5} mole Al_2O_3/1, or $10^{-5.04}$ mole Al_2O_3/1, or $10^{-4.76}$ gm. at. Al/1) and also by measurements of the specific conductivity or a saturated solu-

tion (1.02×10^{-5} mole Al_2O_3/l, or $10^{-4.99}$ mole Al_2O_3/l or $10^{-4.69}$ gm. at. Al/l). Busch[28] has obtained a value of 0.96×10^{-5} mole Al_2O_3/l (which is $10^{-5.02}$ mole Al_2O_3/l or $10^{-4.72}$ gm. at. Al/l) by acidimetric titration of a solution saturated at 20 C. Likewise Jander and Ruperti[29] have determined analytically the concentration of Al_2O_3 in a solution saturated with respect to $Al(OH)_3$ at 12-15 C and have found 0.6 mgs Al_2O_3/l (equivalent to $10^{-5.41}$ mole Al_2O_3/l or $10^{-5.11}$ gm. at. Al/l). All these values agree well enough between themselves, but leave open the question of exactly what form of oxide or hydroxide they represent.

Summary

The potential-pH equilibrium diagram of the system aluminum-water was developed from the standard free energies of the constituents, and the general electrochemical behavior of aluminum deduced from the diagram.

Most of the values of the free energies were taken from the work "Oxidation Potentials" (1952) of Latimer. The following values were calculated from experimental data found in the literature: $\mu°_{AlO_2^-} = -200,710$ cal; $\mu°_{Al_2O_3 \cdot 3H_2O} = -552,470$ cal (bayerite) and $-554,600$ cal (hydrargillite).

The diagram was established by considering the ions Al^{+++} and AlO_2^- and the solid phases Al and $Al_2O_3 \cdot 3H_2O$ (hydrargillite). The diagram indicates the theoretical circumstances in which aluminum should show corrosion, immunity, and passivity, under the hypothesis that the passivation results from the formation of a film of oxide whose stability resembles that of hydrargillite. The stability of aluminum and the different forms of its oxides are discussed. Curves are given of the solubilities of the oxides and hydroxides as functions of pH.

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Corrosion-Resistant Experimental Steels For Marine Applications*

By C. P. LARRABEE

Introduction

THE CORROSION of carbon-steel piling in sea-water installations is most severe in the "splash zone."[1]* Previous exposure tests have shown that Ni-Cu-P (nickel-copper-phosphorus) steels have superior corrosion resistance in this zone. The present paper contains data comparing the corrosion after 1-, 2-, and 5-year exposures, at 1-foot intervals, of 20-foot-long specimens of structural carbon steel and of 6 steels having various combinations of nickel, copper, and phosphorus. It also contains data from a 3.5-year atmospheric test exposed 80 feet from the ocean shore.

Materials and Experimental Work

Sea-Water Tests

In 1951, quadruplicate 20-foot-long, 6-inch-wide specimens of 6 different Ni-Cu-P experimental steels and of carbon steel (sheet-steel piling grade) were exposed at The International Nickel Company's Harbor Island Testing Station at Wrightsville Beach, North Carolina. The experimental steels had yield points of 49,000 to 52,000 psi and tensile strengths of 71,000 to 76,000 psi; the elongations in 2 inches were 29.0 to 34.0 percent. The compositions of these steels are shown in Table 1.

The specimens were placed in the water so that their tops extended above the splash zone while the bottoms were in the mud. A photograph of the specimens at the start of the test is shown in Figure 1; the water in the foreground is part of a 100-yard-wide channel through which tidal currents flow. The relatively minor wave action is parallel to the installation, and the splash zone is narrower than is the case with piling exposed to the rougher water along the open sea coast.

A specimen of each steel was removed after 1-, 2-, and 5-year exposures, and was cleaned and examined. A photograph of specimens taken immediately after removal is shown in Figure 2. The strips were sheared into approximately 1-foot pieces, and the proportionate fraction of the original weight of the 20-foot strips was assigned to each of the pieces on the basis of its length. From the weight after cleaning in a sodium-hydride bath and from the estimated original weight, the average decrease in thickness of each piece was calculated.

Atmospheric Tests

In 1951, quintuplicate 4- by 6-inch specimens of six experimental Ni-Cu-P

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* The area above high tide where the piling either is intermittently immersed in sea water or occasionally splashed by wave action.[1]

About the Author

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steels, a structural copper steel, and two structural carbon steels were exposed on atmospheric-test racks located along the shore about 80 feet from the waterline at Kure Beach, North Carolina. Figure 3 shows the 80-foot site in the foreground of the photograph. The compositions of these materials also are shown in Table 1. Loss-of-thickness

Abstract

Six steels having various combinations of nickel, copper and phosphorous were tested in sea water for exposure periods of one, two and five years, and a comparison made with the corrosion resistance of structural carbon steel. The test specimens measured 20 feet in length and were placed in the sea water so that their tops extended above the splash zone while the bottoms were in the mud. Decreases in thickness were calculated at 20 different levels for each of the Ni-Cu-P steels. It was found that these steels as a class were much more corrosion resistant than the sheet-piling steel to the conditions existing in and above high tide. The superiority was even greater when the steels were exposed to the atmosphere 80 feet from shore. The five-year exposure tests showed that steel containing 0.5 percent Ni, 0.5 percent Cu and 0.12 percent P had the greatest resistance of the steels tested. The attack below low tide was essentially independent of the composition of the steel. Pitting attack was very local and thus severe. In atmospheric tests made 80 feet from the shore, the most resistant Ni-Cu-P steel had a weight loss only 5 percent that of sheet-piling steel. 2.2.3

data from this test after exposures of 0.5, 1.5, and 3.5 years are given in Table 2. Many of the specimens were lost during the October, 1954, hurricane. As shown in Table 2, one or more of the remaining triplicate specimens of all steels were recovered. All the specimens which had been replaced on the test racks after the hurricane were removed in 1955.

Results and Discussion

Inspection of the data in Table 3 shows that the results of the 5-year exposure continue the trends shown by the 1- and 2-year exposure. Despite certain apparent anomalies, which will be discussed later, it is evident that in the most corrosive area, which is immediately above high tide (splash zone), all

Figure 1—Simulated piling test. Size of specimens at right is 0.5 by 20 ft.

501t

Exposed to:

Shells and Mud

Water

Tidal Zone

Atmosphere, including sea-water spray (splash zone)

Figure 2—View of 20-ft. specimens removed after one-year exposure.

TABLE 1—Compositions of Materials Exposed in 1951 in Sea Water and in Marine Atmosphere

Exposure	Material Number	Type	COMPOSITION, PERCENT							
			C	Mn	P	S	Si	Cu	Ni	Cr
SW—MA*	BO1458	0.5 Ni, 0.5 Cu, 0.1 P	0.14	0.44	0.12	0.023	0.044	0.52	0.54	0.009
SW—MA	BO1389	0.5 Ni, 0.2 Cu, 0.2 P	0.13	0.38	0.17	0.023	0.026	0.22	0.55	0.009
SW—MA	BO1457	0.5 Ni, 0.2 Cu, 0.1 P	0.12	0.40	0.11	0.021	0.044	0.20	0.54	0.02
SW—MA	BO1459	0.5 Ni, 0.2 Cu, 0.1 P	0.14	0.42	0.14	0.024	0.042	0.20	0.55	0.02
SW—MA	BO1467	0.3 Ni, 0.2 Cu, 0.1 P	0.16	0.41	0.14	0.023	0.038	0.20	0.28	0.02
SW—MA	BO1456	0.3 Ni, 0.2 Cu, 0.2 P	0.12	0.36	0.17	0.025	0.05	0.22	0.28	0.01
SW—MA	BO1468	Sheet-Steel Piling	0.27	0.53	0.011	0.036	0.007	0.06	0.09	0.04
MA**	D367	Structural Carbon Steel	0.18	0.51	0.010	0.032	0.07	0.05	0.03	0.09
MA	D368	Structural Copper Steel	0.19	0.61	0.013	0.042	0.029	0.23	0.04	0.05

* Sea Water and Marine Atmosphere.
** Marine Atmosphere.

TABLE 2—Losses of Weight of Specimens Exposed to the Atmosphere at Kure Beach, N. C. in 1951[1]

Material Number	Type[2]	Average Decrease in Thickness, Mils[3]		
		0.5 Year	1.5 Years	3.5 Years
BO1458	0.5 Ni, 0.5 Cu, 0.1 P	1.6	7	11(3)[4]
BO1389	0.5 Ni, 0.2 Cu, 0.2 P	1.6	5	14(2)
BO1457	0.5 Ni, 0.2 Cu, 0.1 P	1.6	6	19(2)
BO1459	0.5 Ni, 0.2 Cu, 0.1 P	1.9	3.5	19(3)
BO1467	0.3 Ni, 0.2 Cu, 0.1 P	1.9	6	24(3)
BO1456	0.3 Ni, 0.2 Cu, 0.2 P	1.6	5	23(2)
BO1468	Sheet-Steel Piling	2.6	16	93(3)
D367	Structural Carbon Steel	2.9	18	(0)
D368	Structural Copper Steel	2.9	11	72(1)

[1] Specimens were located approximately 80 feet from shore line at high tide.
[2] Compositions in Table 1.
[3] Calculated from loss of weight of the 4- by 6 inch specimens.
[4] Numeral in ( ) indicates replicate specimens that survived hurricane.

the Ni-Cu-P steels have better corrosion resistance than the sheet-piling steel. On the basis of all the accumulated data, the steel (BO1458) containing 0.5 percent Ni, 0.5 percent Cu, and 0.12 percent P appears to be the most consistently resistant in the splash zone.

The data in Table 3 indicate that the individual average decreases in thickness, as calculated from weight losses, may be somewhat erroneous in a few instances. This situation exists because of assumptions that were made in estimating the correct factional part of the original weight of the 20-foot-long specimen for each subsequently sheared piece. For simplicity, the original piece was assumed to be of uniform thickness and width. Actually, there was a little variation in thickness, but it is believed that the data accurately reveal gross differences in corrosive attack between the various steels. Individual cases in which there appears to have been less attack in five years than in two years probably are caused by a combination of all the factors involved influencing the errors in one direction.

Because of the fact that the shoreward sides of the 20-foot-long specimens were bolted to creosoted timbers (Figure 1), the calculated decrease in thickness of the top 1-foot section (Table 3), is somewhat unrealistic. Also, the corrosion is diminished at the tops of the 20-foot-long strips because there is comparatively slight wave action in the channel where the test was located. The author believes that because of the very large differences between the loss of the sheet-piling steel and of all the Ni-Cu-P steels at the 80-foot atmospheric test lot, in many exposures of actual piling the superiority of the Ni-Cu-P steels would be shown at greater distances above high tide than is the case in this test. Whether or not this is correct will be shown subsequently by tests that were exposed in 1956 at several locations where the spray conditions were much more severe.

The attack on steels immersed in sea water is a function of the availability of the dissolved oxygen at the metal-water interface. If there are small areas where the soluble oxygen is consumed before reaching the metal by diffusion through the rust and the fouling, and large areas where the oxygen remains in contact with the steel, severe pitting attack will result at the areas where there is a deficiency of oxygen. That this occurred on the 20-foot specimens of sheet-piling steel and on Ni-Cu-P steel is shown in Figure 4. The maximum and minimum thicknesses of each of the twenty 1-foot-long, cleaned pieces of the two steels were measured with a ball-point micrometer. As would be expected, the residual thicknesses, calculated from measured weight losses, are between the two extremes.

The data in Figure 4 shows that the minimum thickness of the originally 249-mil thick Ni-Cu-P steel (B01458) in the splash zone was 162 mils, whereas the sheet-piling steel was 0 (perforation). The depth that the pits in the latter would have reached if the specimen had been thicker is unknown. It is evident that the superiority of the Ni-Cu-P steel as measured by loss of weight is greater than when measured by a comparison of the minimum thicknesses. The latter measurement, however, is related to the chance occurrence of two pits exactly opposite each other.

Figure 3—Marine atmospheric test sites (prior to July, 1954 at Kure Beach, N. C. In foreground is shown the 80-ft. test site and in background the 800-ft. test site.

In the splash zone, the apparent resistance to pitting attack of the Ni-Cu-P steel (B01458) is at least three times that of the sheet-piling grade.

Whether bad pitting would occur on each side of sheet-steel piling would depend upon exposure conditions, such as type of fill. Pitting below low tide may be prevented on actual installations by cathodic protection measures.

Attention is called to the comparatively low losses of thickness that occurred near the "mean tide" zone of all specimens. Humble[2] reported that at high tide, steel surfaces below the low-tide zone were anodic to that portion of the same steel in the tidal zone. This results in an acceleration of the attack on the steel below the low-tide zone and a partial protection of the surface in the tidal zone.

The comparatively excellent corrosion resistance of the 0.5 Ni, 0.5 Cu, 0.12 P steel to sea-water-spray conditions is shown in Table 3 and confirmed by the data in Table 2. It should be remembered that a large percentage of the weight loss of all the specimens exposed 80 feet from the shore occurs on the groundward side of the specimens, which are exposed at an angle of 30 degrees to the horizontal and facing the water. The sea salt from evaporation of the spray is not washed from the groundward surface by rain. The severe corrosion of carbon steel and copper steel, when exposed under shelter and near the ocean has been reported.[3]

Table 2 shows that the calculated average losses of thickness of the structural carbon steel (sheet-steel piling grade) and structural copper steel after an exposure of 0.5 year are 2.6 and 2.9 mils, respectively; yet, after 3.5 years they are 93 and 72, respectively. It is of interest that in the industrial atmosphere at Kearny, New Jersey, the calculated average losses of steels very similar in composition to the above steels at Kure Beach were 5.6 and 3.5 mils after an 0.5-year exposure and 10.2 and 6.6 mils, respectively, after a 3.5-year exposure. The greater protective effect of the rust film in the industrial atmosphere is evident.

Summary

The results of 1-, 2-, and 5-year exposure tests show conclusively that in sea-water service the Ni-Cu-P steels as a class are much more resistant than sheet-piling steel to the conditions existing in and above high tide. The superiority is even greater when the steels are exposed to the atmosphere 80 feet from the shore.
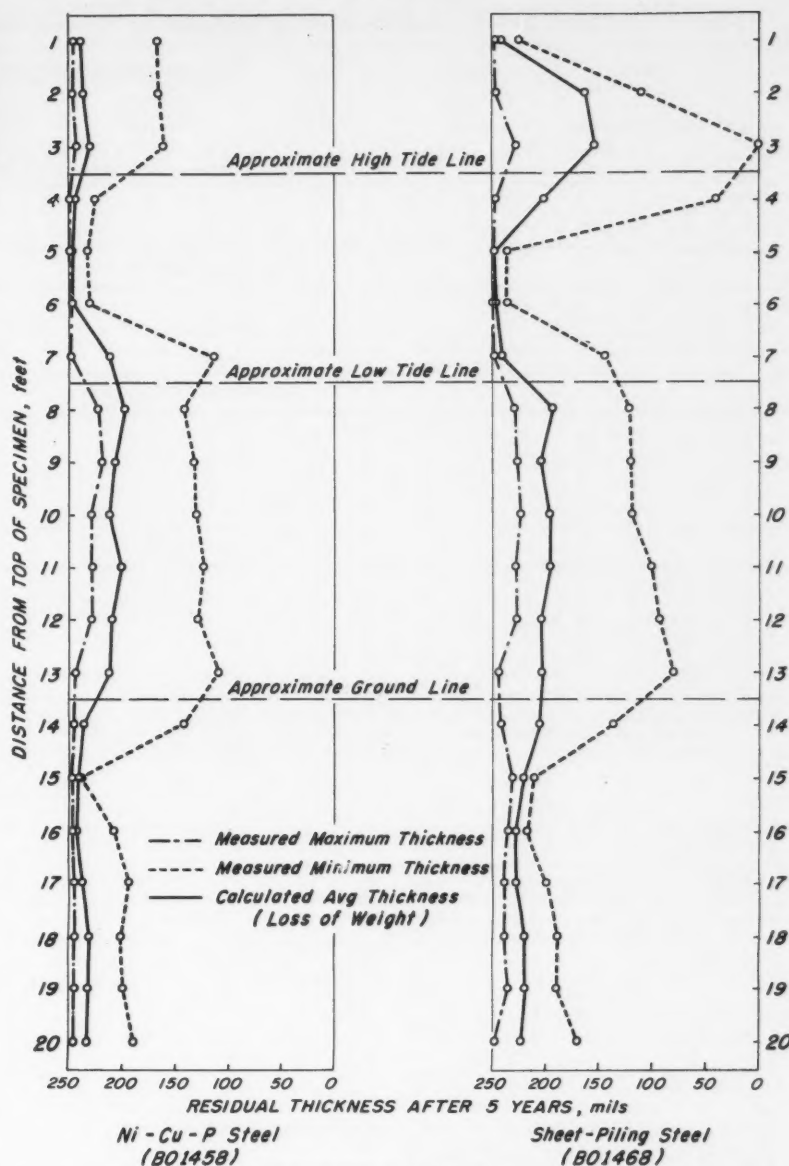
Figure 4—Comparative corrosion on two steels in marine environments.

After five years' exposure in the splash zone immediately above high tide, a steel containing 0.5 percent Ni, 0.5 percent Cu, and 0.12 percent P had the greatest resistance of the six Ni-Cu-P steels tested. The attack below low tide was essentially independent of the composition of the steel, and by calculations based on loss of weight, was about 45 mils, or 4.5 mils, per year for each surface. Pitting attack was very local, and consequently, severe.

During the last two years of a 3.5-year test, the weight loss of the most resistant Ni-Cu-P steel when exposed on the usual atmospheric test racks about 80 feet from the ocean was only 5 percent that of sheet-piling steel.

Present Testing Work

An example of the non-reproducibility of the corrosive conditions at the 80-foot test site is illustrated by the following: In a test exposed just a year later, the same structural copper steel (D 368)

lost only one-half as much during an exposure of 3.5 years, that is 72 mils in the 1951 exposure, 36 mils in the 1952 exposure. Major differences in amount and time of deposit of sea water on the groundward sides of the specimens were probably the major factors. Much larger variations between the losses of replicate specimens occur at the 80-foot site than at any other. For instance, the variation in the losses of the 3 specimens of sheet-piling steel shown in Table 2 was 57 grams.

Comparative tests of samples from a 100-ton heat of an experimental steel containing 0.5 percent Ni, 0.2 percent Cu, and 0.12 percent P, and of carbon steel, have been exposed at Boston, Massachusetts; Wrightsville, and Carolina Beach, North Carolina; Mobile, Alabama; Harvey, Louisiana; Caplan, Texas; and Seattle, Washington.

Plans are being made to compare the resistance of a 0.5 Ni, 0.5 Cu, 0.12 P steel and sheet-piling steel in similar

TABLE 3—Average Decrease in Thickness of 20-Foot Specimens in Sea Water*

Avg. Feet From Top	B01468 Sheet-Piling Steel			B01458 Ni-0.54% Cu-0.52% P-0.12%			B01389 Ni-0.55% Cu-0.22% P-0.17%			B01457 Ni-0.54% Cu-0.20% P-0.11%			B01459 Ni-0.55% Cu-0.20% P-0.14%			B01467 Ni-0.28% Cu-0.20% P-0.14%			B01456 Ni-0.28% Cu-0.22% P-0.17%		
	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils	1 Yr, Mils	2 Yr, Mils	5 Yr, Mils
0.5**	9	7	9	3	4	11	4	7	12	5	9	30	7	7	24	4	8	9	6	13	10
1.5	9	13	87	3	7	13	3	7	16	4	9	30	6	9	18	3	7	21	5	12	21
2.5	31	46	98	8	9	17	8	7	26	8	11	54	9	9	30	7	18	45	9	19	73
Approximate High Tide Line																					
3.5	31	18	48	4	7	4	5	8	9	5	7	9	6	6	7	4	20	6	5	11	22
4.5	1	7	1	2	6	1	4	6	2	4	8	1	3	6	2	2	5	1	2	8	2
5.5	0	7	2	1	5	1	3	5	2	5	6	2	3	7	7	2	5	3	3	8	2
6.5	9	27	14	13	23	37	11	18	34	4	27	41	6	24	29	9	21	28	11	32	24
Approximate Low Tide Line																					
7.5	19	30	56	14	24	52	16	25	52	13	29	64	15	25	53	14	27	42	15	28	46
8.5	16	29	45	15	21	41	16	22	44	9	25	49	14	29	42	15	32	38	14	24	34
9.5	14	22	52	15	22	38	17	24	41	10	25	49	15	30	49	17	32	43	15	21	32
10.5	18	22	53	14	22	48	17	15	40	10	24	49	16	31	42	17	27	41	20	27	32
11.5	14	24	45	8	21	39	13	24	35	10	25	49	8	28	42	13	34	37	13	27	32
12.5	4	10	46	3	9	37	3	22	38	4	16	46	4	10	32	7	14	35	16	10	33
Approximate Ground Line																					
13.5	3	10	45	3	12	13	3	8	24	4	14	37	5	15	11	8	11	12	3	10	18
14.5	3	12	29	3	9	6	4	9	24	3	11	24	3	11	6	6	11	7	4	12	17
15.5	3	9	21	3	10	5	3	11	5	2	9	14	3	24	5	7	9	6	6	13	18
16.5	3	9	22	3	20	10	3	22	13	7	7	11	6	8	7	5	9	15	6	13	28
17.5	5	5	30	5	14	18	4	14	22	9	8	10	8	7	12	7	9	28	6	13	31
18.5	4	14	30	3	20	12	5	10	15	8	7	10	7	7	22	4	14	25	3	9	34
19.5	10	10	27	6	16	15	9	18	24	3	9	17	8	10	39	6	24	38	3	11	31

NOTE: Approximate Mean High Tide 2 to 3 feet from tops of specimens; approximate Mean Low Tide about 6 feet from tops of specimens.
* Specimens were exposed in 1951; figures quoted were calculated from losses of weight.
** Unrealistic values because of partial protection from top supporting member (see Figure 1.)

locations and particularly where periodic maintenance above high tide is very expensive. Such is the case with the offshore oil-drilling rigs in the Gulf of Mexico and in the Pacific. The steel's widest application on these rigs might be for structural sections rather than for piling.

References

1. H. A. Humble. The Cathodic Protection of Steel Piling in Sea Water. Corrosion, 5, No. 9, 292 (1949).
2. H. A. Humble. Corrosion, 5, 292 (1945).
3. F. L. LaQue. Corrosion Testing. 1951 Edgar Marburg Lecture, Proc. ASTM, 51 (1951).

DISCUSSION

Question by Cornelius Groot, Richland, Washington:

The corrosion of your 20 foot strips is a classic example of non-uniform corrosion and illustrates the difficulty of measuring and expressing non-uniform corrosion. Have you considered using the 20 foot strips as tensile specimens, thereby obtaining the reduction of cross-section at the weakest point?

Reply by C. P. Larrabee:

Mr. Groot's suggestion of using the entire 20-foot strip as a tensile specimen

to obtain the maximum reduction of cross-section is excellent, but the equipment necessary for this measurement is not available to us. As another numerical calculation (besides calculated average reduction of thickness by loss of weight of one-foot-long intervals) it might be feasible to determine the breaking point of the section immediately above high tide, where occurs the greatest corrosion. In this way a 3 to 4-foot piece could be used, rather than the entire 20-foot piece. However, in either of the alternate methods, it would be necessary to reserve unexposed samples for comparison purposes, which was not done in our experiment.

Question by John A. H. Carson, Pacific Naval Laboratory, HMC Dockyard, Esquimalt, British Columbia:

It is my understanding that cathodic deposits are not normally encountered on steel in sea water at cathode potentials of less than —0.90 volt vs a silver-silver chloride electrode. Since the maximum anodic potential which could be expected in the couple—steel (or rust scale) in the tidal zone to steel below the low tide level is less than —0.80 volt (vs the same reference electrode),

cathodic potentials must be equal to or less than this. Can you explain the occurrence of cathodic deposits in the tidal zone of continuous sheet steel piling?

Reply by F. L. LaQue:

By way of a comment on the question raised by Mr. Carson in his discussion of Mr. Larrabee's paper, it may be noted that deposition of calcareous deposits on cathodic surfaces in sea water is probably not a simple function of potential or even cathodic current density. Precipitation of calcium and magnesium compounds from sea water will result from anything that will increase the pH of the sea water, as by the alkali formed by cathodic reactions. The chance of developing sufficient alkalinity to bring about this precipitation will be influenced by the opportunity for alkaline compounds to concentrate in the layer of solution next to the cathode. This, in turn, will be greater in a stagnant solution than in a strongly agitated one. Consequently, the deposition of calcareous deposits will be determined not only by the observed potential, but also by the current density and agitation as well.

Any discussions of this article not published above will appear in the June, 1959 issue

Locating Underground Contacts And Open Couplings By Electrical Measurements*

By CHARLES L. WOODY

Introduction

THE EFFECTIVENESS of any cathodic protection system may be completely nullified by a single underground contact or open coupling. A major consideration in the operation and maintenance of a cathodic protection installation may be the cost of locating these underground contacts and open couplings. Such an operation may prove extremely difficult in the city distribution system due to the nature of construction and above-ground interference. Unlike the cross country pipe lines, the city distribution system may involve the running of lines where there is little regard to physical separation from the other underground structures within the city area.

A further complication in the operation of electrical insulation and continuity of the city distribution system is the small pipe sizes involved. Normal pipe sizes range from ¾ inch to 16 inches. The types most commonly used for mains are the 4 inch, 2 inch, and 1¼ inch sizes. It is common practice to use large quantities of 1 inch pipe or ¾ inch pipe for service lines. If this smaller pipe is buried 30 to 36 inches in an 8 inch to 10 inch ditch under a paved street, it is easy to see why exactly locating and making electrical contacts with this pipe would be a difficult operation.

The purpose of this paper will be to describe and illustrate some rather simple tests which can be used to determine the location of electrical contacts or open couplings in the underground piping.

Figure 1 shows the piping layout of a typical small distribution system constructed since the days of cathodic protection. Insulating type fittings were provided during the time of construction to electrically isolate this system into small, approximately 5,000 feet each, electrical units. This is a relatively new system and ideally constructed for the operation and maintenance of cathodic protection. The policy of isolating a system into small electrical sections of 5,000 feet to 10,000 feet each is believed to be sound and should be followed when installing cathodic protection on the older systems. This is considered a necessary part of cathodic protection installation and maintenance and should be borne in mind when the following tests are discussed. Of course, many of the tests to be discussed are equally applicable to longer system or pipe line use. But, for the purpose of the paper, attention and stress will be placed on small size pipe in relatively short sections.

In addition to sectionalizing the city

About the Author

C. L. WOODY is employed by United Gas Corporation, Houston, Texas. His corrosion control work began more than 12 years ago on natural gas pipe lines of Mississippi Power & Light Co. and Louisiana Power and Light Company. He was employed by Ebasco Services, Inc., New York as an electrical engineer before joining United Gas Corp. He has a BS in electrical engineering from North Carolina State College.

distribution system, it is necessary to provide some type of test points if they are not provided by means of welded and coated service lines. In many systems the service lines provide excellent test points as they may be located an average of every 50 to 60 feet along the distribution mains, coated, electrically continuous, and insulated above ground at the meter installation. At other locations the test points such as indicated in Figure 2 may be provided. These test points are usually located in paved areas.

Perhaps the most useful measurement and the easiest made in checking a distribution system is potential measurement. For the routine cathodic protection installation, potential measurements normally are the only measurements required. Figure 3 indicates the most common method of making potential measurements in the distribution system. Note that the test point indicated is that of an insulated meter loop. Either pipe-to-soil or pipe-to-water potential measurements may be made and used as satisfactory potential measurements. In the case of pipe-to-water pipe measurements it is important that the water pipe reference be made to a part of a large, well-established system and not to a local service line that may be insulated at the main itself.

Another item of information that is desirable is a complete record of the original system. A complete potential survey is indicated in Figure 4. As will be noted, pipe-to-soil, water pipe-to-soil, and pipe-to-water pipe potentials are indicated with the cathodic protec-

Abstract

The city distribution system presents a unique problem in cathodic protection installation and maintenance because of the multiplicity of underground piping and cable systems. The paving or hard surfaces usually present limits visual inspection and electrical test connections to the piping to an absolute minimum.

This paper is not intended to be a theoretical treatise on the underground electrical circuit, but instead gives a practical approach to the problem of locating contacts and open couplings. While some of the methods used may not be entirely correct from a theoretical standpoint, in application they have resulted in a satisfactory solution to underground open couplings and contact problems. The equipment discussed includes the ammeter, volt meter, pipe locator, current interrupter, and other readily available variations of these instruments. The discussion deals primarily with the practical use, limitations, and results that may be obtained by trained and experienced personnel. The emphasis is placed on experience and interpretation of results observed rather than on a theoretical approach. 4.5.3

tion current both "on" and "off." Also, a column is provided for the so-called DV or change in potentials due to cathodic protection currents. This type of potential record can be invaluable when shooting troubles later on. It is also valuable when attempting to locate open couplings or contacts, since the potential gradient on the system is very clearly indicated and the general suspected area is pointed out.

One other measurement that is considered a must when shooting trouble on a distribution system is that of current drain. Normally the distribution systems are protected with galvanic anodes so the anode current measurement is considered a necessity. Figure 5 indicates the common circuit used for measuring anode currents. This is a standard zero resistance ammeter circuit. It is considered by many to be the only satisfactory means of measuring anode current when inserting the ammeter directly in the current lead.

Figure 6 illustrates a second method of current measurement using a permanently connected shunt installed in the anode lead. Current measurements are made by measuring the voltage drop across this permanently connected shunt. This method is also satisfactory in that no changes are made in the anode circuit when current measurements are being made.

While the above-mentioned tests are not considered a part of locating contacts and couplings by electrical measurement, they are believed to be the first and essential measurements to make before attempting to locate contacts or open couplings. The potential measurements would be used to indicate the existence of contacts or open couplings, supported by the current measurements to determine proper operation of the anodes.
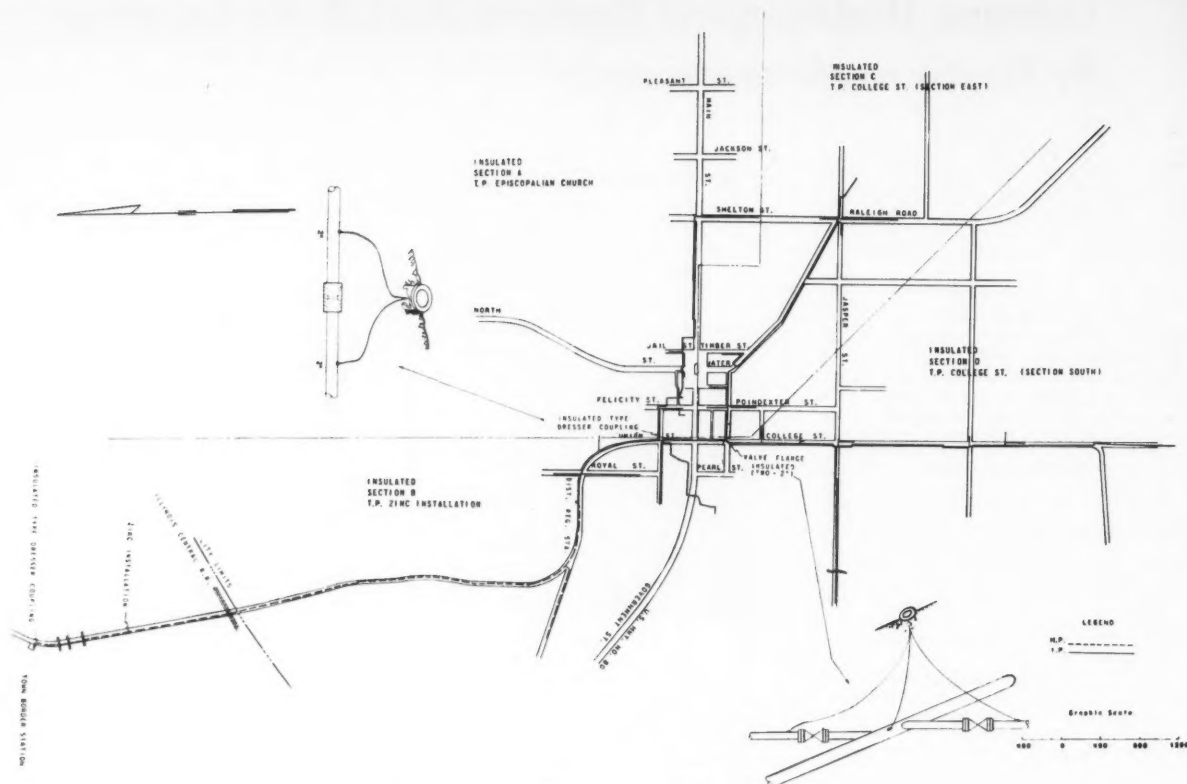
Figure 1—Example of sectionalization of a cathodic protection system.

Figure 2—Test points.
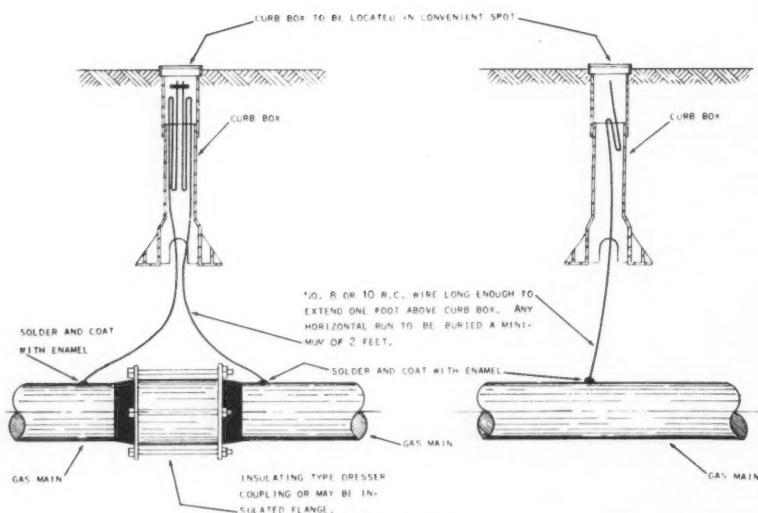
Figure 3—Method of making potential measurements.

Locating Contacts—Pipe Locator Method

Assuming that it has been definitely determined that low potentials exist due to contacts, the most common and most rapid method of locating such contacts is by the use of a contact type pipe locator as illustrated in Figure 7.

One pipe locator that is in general use is the Wahlquist type which places an audio tone on the pipe. This audio tone is actually a noise tone created by a vibrator rich in harmonics and with basic frequency in the order of 100-200 cycles per second. This audio voltage is applied between the pipe and the ground. The method of connecting the transmitter to the pipe line and ground is very important since the actual tone placed on the pipe is a function of the circuit impedance. The lower the circuit impedance, normally, the greater the tone current that may be placed on the pipe. The tone or audio current will follow the pipe until it can leave it to the soil and return to the transmitter through the soil. If no contact exists, this will be through coating faults to the earth which is a relatively high resistance path. A contact with a relatively large structure, such as an underground water system, would provide a low impedance path and tend

Figure 5—Measuring anode current by "zero" resistance ammeter method.

LOCATION	P/S VOLTS			W/S VOLTS			P/W VOLTS		
	ON	OFF	DV	ON	OFF	DV	ON	OFF	DV
Anode Inst. 1600 Main St.	-0.98	-0.72	-0.26	-0.64	-0.65	+0.01	-0.34	-0.07	-0.27
1501 Park St.	-0.90	-0.69	-0.21	-0.60	-0.60	0	-0.30	-0.09	-0.21
800 Collier St.	-0.94	-0.71	-0.23	-0.61	-0.60	-0.01	-0.33	-0.11	-0.22
City Gate Station	-0.97	-0.75	-0.22	-0.60	-0.58	-0.02	-0.37	-0.17	-0.20
612 Sandow St.	-0.88	-0.68	-0.20	-0.56	-0.56	0	-0.32	-0.12	-0.20
1420 Bell St.	-0.90	-0.69	-0.21	-0.57	-0.56	-0.01	-0.33	-0.13	-0.20
2811 Main St.	-0.85	-0.70	-0.15	-0.56	-0.56	0	-0.29	-0.14	-0.15
1326 Adams St.	-0.86	-0.69	-0.17	-0.60	-0.59	-0.01	-0.26	-0.10	-0.16
1202 Eagle St.	-0.85	-0.68	-0.17	-0.60	-0.60	0	-0.25	-0.08	-0.17

Figure 4—Example of potential check-out.

Figure 6—Installation of Holloway shunt.

to carry off a major part of the audio tone. A contact of this type would be readily indicated by the change in tone on the gas main.

Figure 7 illustrates a rather ideal situation in which the tone is placed on a coated pipe and is followed by means of the pipe locator receiver until it reaches the point of contact at which a part of the tone leaves the pipe. In the case illustrated, it is assumed that the contact is with a line traveling in a direction perpendicular to the cathodically protected line. Normally, a strong tone will leave the pipe locator transmitter and follow the gas main to this point of contact, there branching off on the contacting foreign line. Some tone will continue on the gas main but may be very weak, or in some cases it may be relatively strong. The actual strength of the tone on the contacting line may be of little significance, but the fact that the tone is leaving the gas line and being carried away on the foreign line is the indication of contact.

Care must be taken to actually determine that tone is being carried away on the foreign line and not leaving the protected line through a coating fault. This usually can be done by accurately checking for nulls over the foreign line; if the line is conducting the tone, a null will be readily indicated. A null is located by holding the pipe locator receiver in such a manner that the plane of its antenna is parallel to the field about the pipe. At the exact point at which the line of force created by the tone current is parallel to the plane of the antenna, no signal will be received by the pipe locator reciver. If the current is spreading through the earth, no point of null will be obtained over the suspected line.

To further complicate the locating of contacts by the use of pipe locators, the underground location of pipes may be as indicated in Figure 8. In this case,

Figure 7—Locating contact using pipe locator. Note: pipe locator transmitter may be connected between gas pipe and water or gas pipe and anode lead.

the two mains are parallel—maybe only a few feet apart—with laterals from either main extending over the other at right angles. Assuming that one of the laterals is in contact with both mains, both the gas main and the foreign line may carry tone. When this is true, it is usually possible to follow the tone on the gas main to a point at which it drops off very noticeably. At this point, it may not be possible to locate the source of contact, such as a lateral, due to the close proximity of the two mains. Normally, if the pipe locator is connected between the protected line and the contacting foreign line, this point of contact may be rather sharply defined even though the contacting line itself may not be indicated. It is usually desirable to carefully locate the lateral

lines in this case in order to definitely determine the contacting point.

Figure 9 shows a satisfactory method of locating the lateral lines or service lines extending from a main. In this case, the pipe locator receiver is carried in such a manner that the plane of the receiver antenna is perpendicular to the main and parallel to the lines of force generated by the tone current on the main. Any lateral line carrying an appreciable amount of tone will be readily indicated when the receiver held in this manner is moved parallel to the main. If the lateral is in contact with a foreign line due to an uninsulated meter or underground contact, it would be readily indicated by an unduly large amount of tone being carried on this lateral. If a contact exists very close

Figure 8—Locating contact using pipe locator. Note: if driven ground is used, little or no tone is to be expected on water main unless contact exists. When the water main is used for ground connection there will be a strong tone on the water main even if no contact exists.

Figure 9—Method of testing piping running at an angle to the main.

Figure 10—Locating contact by IR drops.

to the gas main, little tone will be expected although sufficient tone should be present to locate the lateral.

Interrupted Current Method

Occasionally a contact will exist that defies positive location by means of the pipe locator. These contacts usually exist at busy intersections or in other areas in which it is very difficult to uncover the mains in the vicinity to find the contact. A method of locating contacts of this nature is indicated in Figure 10. This is considered a rather scientific approach in that it is rather difficult to do and requires very careful measurements. Considerable time may be needed to actually conduct this test. The test is conducted in the following manner: an interrupted current is induced on the gas main at a point remote from the suspected point of contact. This interrupted current is used so that it may be readily identified to prevent confusion with galvanic currents that may be present. The discussion when referred to current will be to the interrupted current as distinguished from the galvanic currents that may be on the line.

Reference may be made to Figure 10, for identification of the symbols and number reference used in the following discussion. First, an IR or voltage drop is obtained on the current source side of the contact. This measurement is referred to as V_A across a distance of L_1 feet. A similar measurement is made on the other side of the contact. This measurement is referred to as V_B measured across a distance of L_2 feet. The voltage or IR drop between contacts or test spans A and B is measured (ie., between test points 2 and 3). The IR drop or voltage per foot is calculated for section A and section B. The IR drop in section A should include current in section B plus the current that is flowing off or being collected from the contact. This total current would flow from the contact to test point 2; that is, distance K. From a simple ratio, this distance X may be determined by calculations. The distance X times V_1 plus the distance Y times V_2 would equal voltage V_e, or the voltage measured between test points 2 and 3. This simplifies to the ratio $X = \frac{V_e - V_2 D}{V_1 - V_2}$. The distances indicated as X and Y may be readily calculated, and both distances should be calculated to use as a check on each other.

From experience, this method of locating contacts in congested areas has proven very effective at times, but it must be pointed out that if potentials across each test section are not very carefully measured, erroneous results may be obtained. The most successful method of locating contacts by this means has been by using a very low resistance, low current millivoltmeter and relatively short lengths of pipe such as may be uncovered in a normal bell hole.

Figure 11 shows the circuit normally used for measuring potentials across short lengths of pipe. As will be noted, correction is made for the lead wires and contact resistance is carefully checked. A word of caution—if contacts are made to the pipe by means of thermit welds, it is absolutely necessary that the welds be allowed to cool before making potential measurements because the thermal potential on a Cadweld joint may exceed the IR drop over a

CALCULATED VALUES

$V_1 = \dfrac{V_A}{L_1}$ volts drop per foot

$V_2 = \dfrac{V_B}{L_2}$ volts drop per foot

X = distance to contact measured from test point #2. (If test point #2 is a service, measurement is made along main from point of service connection.)

$X = \dfrac{V_C - V_2 D}{V_1 - V_2}$

MEASURED VALUES

V_A = volts

V_B = volts

V_C = volts

L_1 = feet of gas main

L_2 = feet of gas main

D = feet of gas main

Alternate means of contacting gas main:

(1) Permanently installed test wire.

(2) Probe rod with hardened and sharpened tip.

$$R = \frac{V}{I}$$

$$R = \frac{DV}{DI}$$

$$\text{Correction factor} = \frac{\begin{bmatrix}\text{Internal instrument resistance}\\\text{for range used}\end{bmatrix} + \begin{bmatrix}\text{External test lead}\\\text{resistance}\end{bmatrix}}{\text{Internal instrument resistance for range used}}$$

Figure 11—Method of making IR drop measurements.

Figure 14—Locating defective flange insulation by the pipe locator method (small pipe).

Figure 15—Locating defective flange insulation by the pipe locator method (large pipe.)

Figure 12—Method of locating contacts by IR drop on water mains.

ENERGIZING BY METHOD A: Measure IR (voltage) drop per foot at A, B, and C produced by interrupted current applied by method A. Contact will be indicated by smaller IR drop per foot at B and C than at A.

ENERGIZING BY METHOD B: Determine direction of current flow in water mains and unprotected lines produced by interrupted voltage applied by method B. Contact will be indicated in section E by current in section F flowing in opposite direction to that in Section D.

Figure 16—Method of checking insulating fittings by measuring insulation resistance.

WHEN METER INSULATION IS GOOD, STRONG TONE WILL BE HEARD ON GAS SERVICE AND WATER SERVICE. WEAK TO NO TONE WOULD INDICATE UNINSULATED METER.

Figure 13—Locating defective meter insulating fitting with the pipe locator.
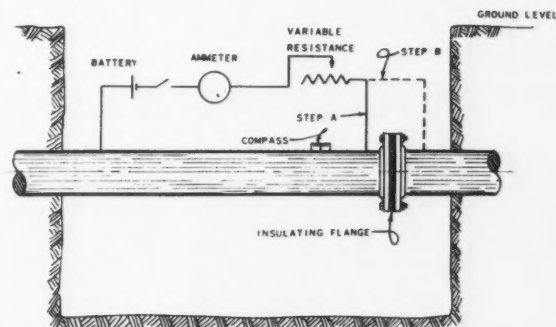
Figure 17—Method of checking insulating fittings using a compass.

short length of pipe by many times, making the calculation appear ridiculous.

It may be impractical to attempt to make four contacts with a main. In such cases, assuming that no contacts with the main are readily available, a different approach may be made. By placing an interrupted current on the protected gas main either between the main and a ground, such as anodes, or between the main and the suspected water line, it may be possible to follow the current on the water main itself to determine the point at which the current flow on the water main reverses (i.e., the point where it tends to leave the water main and collect on the gas main). This is illustrated in Figure 12. The current or current indication on the water main may be found by observing potentials between adjacent water services. In this case, the actual scalar values of potential measurements have little meaning as most water mains have mechanical or lead joints of some type, and the observed currents may be the currents flowing on the overhead power neutral. The only indication that is believed to have any significance is the indicated direction of current flow. By following the water main from service to service and observing indicated direction of current flow, it is usually found that after the point of contact has been passed the induced current has been reversed and is flowing in the opposite direction. Of course, care must be taken to give the

High Resistance Dresser
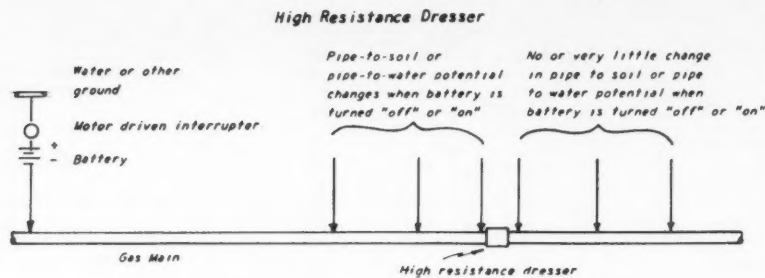
Figure 18—Locating open dresser couplings by pipe-to-soil method.
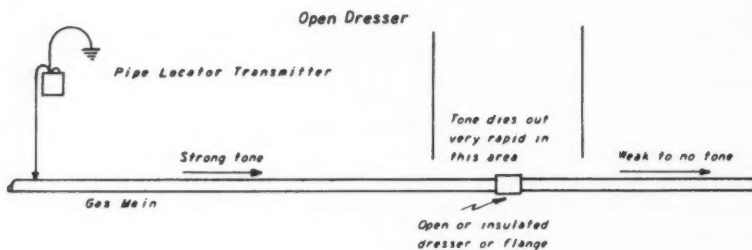
Open Dresser

Figure 19—Locating open dresser couplings by pipe locator method.

Low Resistance Dresser

$V_1 = V_2 = V_4 = V_5$, V_3 will be greater than other voltage drops V_1, V_2, V_4 or V_5
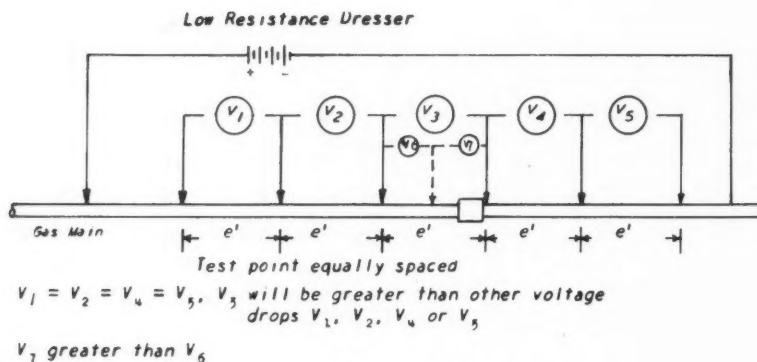
V_7 greater than V_6

Figure 20—Locating open dresser couplings by the IR drop method. The voltage drop measured across the section in which the dresser is located will be greater than voltage drop across any section of equal length.

proper consideration to laterals or other conductors that may affect the indicated current flow on the main. As might be imagined, this method from a scientific standpoint is of rather doubtful value. But actual experience has indicated it to be a very rapid method of locating the general area of the stubborn contacts. Once the general area is located by this method, the suspected points of contact may be readily located by using pipe locators either to search for a point at which the tone is leaving the gas main or to locate the piping in the suspected area and from their physical locations determine the possible points of contact.

Testing Insulated Fittings—Pipe Locator Method

Both insulating and non-insulating fittings may be tested for effectiveness with a contact type pipe locator. For instance, Figure 13 shows a very easily applied and very useful test for deter-

mining the effectiveness of insulating fittings. This test is conducted by connecting the pipe locator transmitter directly across the insulating fittings and checking for tone leaving the area. If the fitting is non-insulating, the pipe locator transmitter will be shorted out and no tone will be found leaving the area. If the insulation is effective, the tone will be found leaving the area on both the gas pipe and water pipe. This test is recommended primarily for small diameter pipe and above-ground fittings.

Underground flanges may be checked, using the pipe locator as illustrated in Figures 14 and 15. In the case of Figure 14, this test may be valid only on small diameter pipe. Large flanges may have sufficient capacity between flange faces to permit transmittal of pipe locator tone with little or no attenuation. In this case, the tone may be going through the insulating flange through the capacitive coupling rather than through a DC coupling. In Figure 15,

the pipe locator transmitter is connected directly across the flange to be tested, and the same result should be attained as previously indicated on the small above-ground insulating fittings. In this case, if the fitting is shorted out or of very low resistance, little or no tone will be found leaving on the connecting pipe line. It is considered to be very valid and reliable test for insulating fittings on mains of the size normally used in distribution systems.

Measuring Insulation Resistance

Insulating flanges may be checked by the ammeter, voltmeter method, as indicated in Figure 16. In this test, a known current is applied across the exposed insulating fitting. The voltage drop across this fitting is also measured. An IR drop measurement is made on the pipe on one side of the flange and the current flow in the pipe is calculated. The actual current flow through the insulated fitting, assuming no current flow in the pipe from other sources, would be the difference between the battery current and current produced in the pipe by this battery current. The resistance of the insulating fitting may be calculated from Ohm's law. The major difficulty in applying this test is the fact that it requires a relatively large bell hole since the IR drop in the pipe leaving the flange should be measured along a length of pipe not in contact with the soil. It also may require very sensitive meters when the current applied is small or the pipe diameter is large. However, it is very easily conducted on small diameter pipe when a relatively large amount of current is available for application across the flange.

Underground insulating fittings may be checked by the bridge method without resorting to a large bell hole. While this method gives theoretically correct results, it is considered rather difficult to perform and is not included in this discussion.

Compass Method

Figure 17 illustrates a very simple method of checking insulating flanges. This circuit is used in one of the commercially available flange test sets. The principle of operation is that of applying a current across the exposed insulating flange, and by means of a compass observing the indication of current flowing in the section of pipe between the point of application and the insulating flange. The compass may be calibrated by applying the current across the pipe section itself as indicated by connection A, or step A, see Figure 17, and then across the insulating flange as indicated in step B. If the deflection is the same in both cases, it can be assumed that the flange is shorted out for all practical purposes. The advantage of this test is that very simple equipment is used and the results are reasonably reliable. The use of the ammeter and variable resistance, as indicated in the drawing, is optional, being simply a matter of refinement or personal choice. One word of caution—when using this type of test, it is necessary that the connecting lead wire be well away from the pipe in order to eliminate any influence it may have on the compass.

Locating Open Couplings

Another very common source of difficulty in a city distribution system is open couplings. They are particularly
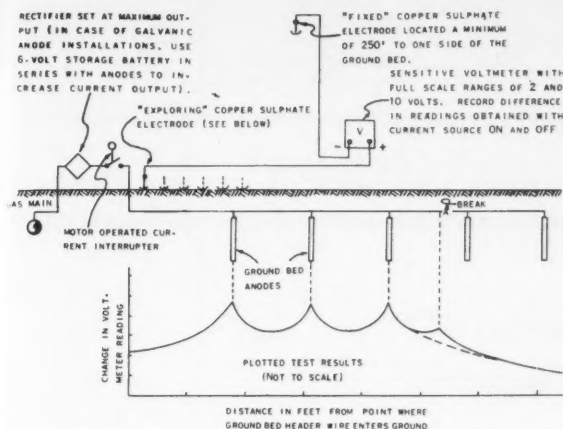
Figure 21—Locating broken anode lead wires.
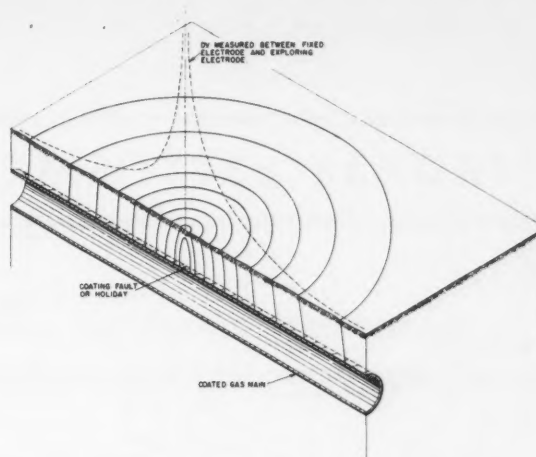
Figure 22—Equipotential lines from coating fault.

annoying since there is no known short-cut for determining their existence or location. Normally, open couplings are indicated when the potential is high in one area of the protected section and low in another. Figures 18, 19, and 20 indicate the normal test procedures used for locating open couplings.

The test illustrated by Figure 18 is the most direct insofar as it is only a matter of probing the pipe and making potential measurements, either pipe-to-soil or pipe-to-water as the case may be, along the pipe. The point of potential drop would be the location of the open coupling. The test is very reliable in the case of high resistance couplings when there is an appreciable potential drop across them caused by normal cathodic protection or test current. It is believed that this test is self-explanatory and commonly used.

The test illustrated by Figure 19 is of doubtful value in that the pipe locator tone may or may not decrease sharply at the coupling due to spread in the soil. The method of conducting this test is to induce a pipe locator tone on one section of the pipe and to follow the tone along the pipe. If a coupling is wide open, little to no tone is expected to go through it. However, this may not be entirely true in the case of a large diameter coupling having considerable capacity or in the case of some soil conditions in which the current may by-pass the coupling. In general, this test is recommended only for an indication that an open coupling exists and is not recommended as a means of determining its exact location. It may be used quite successfully as a preliminary test and followed up by the test of Figure 18.

Figure 20 illustrates perhaps a more positive method of locating couplings. This is done by placing an artificial current on a length of pipe line. Two bars are used to contact the pipe, and the IR drop along the pipe is measured. Indication of the coupling between the two exploring bars would be a higher than normal IR drop between these bars. This method may be used successfully for locating even low resistance couplings, and if care is taken the indication is very reliable. The thing to watch for in this test is to be sure that good

bar contact is obtained and that the meter is connected only when the bars are in firm contact with the pipe; otherwise, there may be a volt or more impressed on two or ten millivolt scale.

In comparison with the previous methods, this test has the advantage that sufficient current can be introduced on the pipe to give a relatively large reading across very low resistant couplings. A disadvantage is the fact that four contacts must be made with the pipe (two for current carrying probes and two for the potential exploring probes).

Locating Broken Anode Leads

Quite frequently, due to the activities of other underground operators in the city distribution system, lead wires are cut or broken between anodes. A broken lead wire between the pipe and the first anode is quite obvious and normally no tests are made, but reference is made to the installation drawing to locate the first anode in order to run a new lead. Broken leads may be suspected when the anode current output is low.

The simplest way to check anode leads or locate breaks between anodes is to measure the soil potentials over the anode to remote electrode as illustrated in Figure 21. Active anodes are indicated by high negative potential points to a remote electrode in the case of galvanic anodes, or high positive potential points in the case of impressed current anodes. This potential may be in the order of $\frac{1}{2}$ volt or more compared to potentials between the anodes, and as a rule it is very clearly defined. The active anodes can be readily staked out and, of course, the break would be between the last high potential point and the following anode that gives no indication. Many times if the break involves some bare wire, the actual end of the wire may be located by carefully observing the potential along the surface of the earth. Anyone who has not run this type of test may be quite surprised at the actual potential existing on the surface of the earth over the anode location.

The same test may be applicable to locating distribution anodes and determining the relative current output. The value of the anode current output may

be roughly estimated from the earth's potential swing in the case of uniform soil.

Locating Coating Holidays—DC Method

Coating holidays may be considered as a contact in the case of high resistance coating. One method of locating these contacts is by the use of the "Pearson" type locator. Experience on city distribution systems has shown that high AC noise levels in many cases have obscured the relatively small tone which indicated coating faults.

A second method quite similar to the "Pearson" method, except that DC current is used, may be more successful on the city distribution system. The theory of this test is indicated in Figure 22. In this test, interrupted DC current is impressed on the line to be inspected. Potential gradients are measured over the surface of the earth by using two electrodes. One electrode is located at a convenient point over the pipe and the second electrode is advanced along the pipe, observing the potential swings as indicated in Figure 23. The normal procedure is to hold one plug stationary and move the other along the pipe making measurements at approximately 10 feet intervals until a region of potential swing as caused by the interrupted current is found. The exploring plug is then moved along at shorter intervals until the point of maximum potential swing is located. In uniform soil the actual size of the coating flaw may be estimated from the relative potential swing. It is not necessary to place the stationary reference plug over the pipe. It may be located in any area of minimum potential swing. Usually the reference plug is placed in the area which have been explored and found to contain no appreciable potential swing.

One thing to watch closely is foreign lines that may be carrying interrupted currents. Normally the potential swing on these lines will be of opposite polarity to that of the pipe being inspected. This method is very fast and can be conducted even in areas of relatively large earth currents, since the exploring current is interrupted at known intervals and can be readily identified, even though it is a relatively small portion of the total earth current.
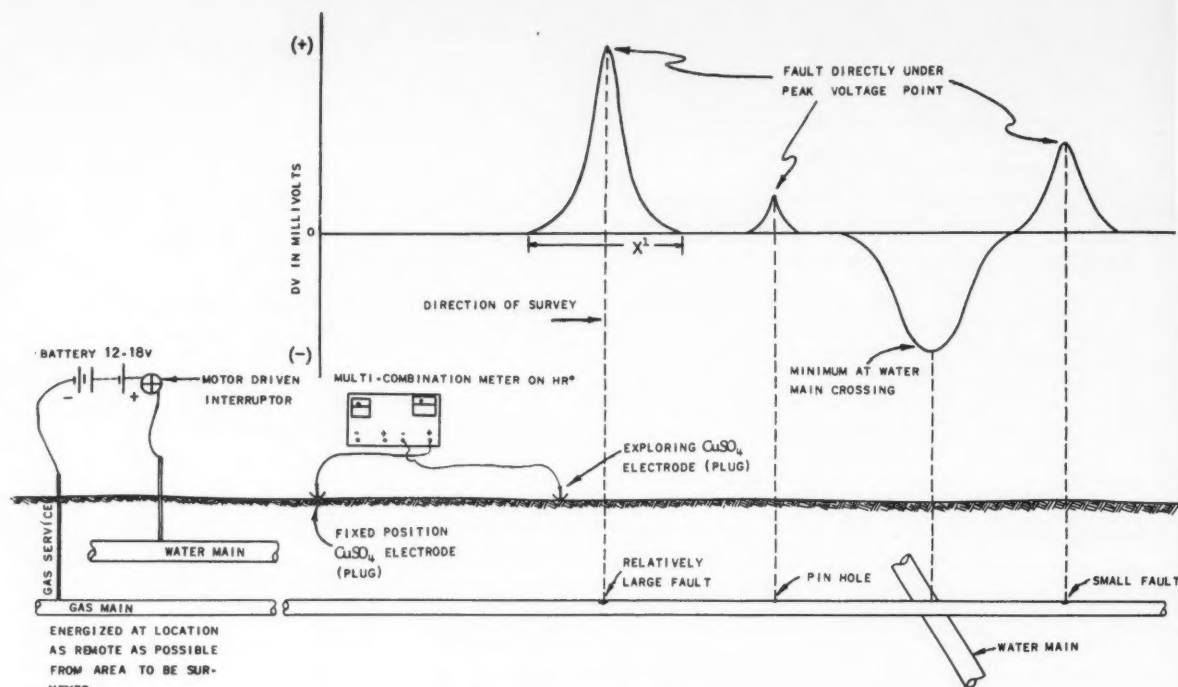
Figure 23—Locating coating faults by dc method.

Conclusions

The tests indicated in this discussion are believed to be practical approaches to the problem of locating contacts, open couplings, insulating couplings, and coating holidays on pipe sizes normally encountered in a city distribution system. The tests are equally applicable to pipe lines but may, in many cases, be relatively slow when used on a long pipe line. However, once an area of suspected trouble is located, the previously indicated tests would be applicable even on a long pipe line and could be used to advantage in many locations.

DISCUSSION

Comments by Daniel R. Werner, American Telephone and Telegraph Company, Kansas City, Missouri:

The use of the surface potential method of measurement was mentioned in the paper to locate anodes discharging current into the earth. If the current to the anodes is broken periodically by an interrupter and the surface potential gradient readings taken with the current on and off, an analysis of the difference of the two readings will show up many things. The disturbance in the earth gradient is under the control of the investigator and this method will be found useful in locating anodes, opens in insulated wires buried in the earth (the open end of the wire must be in contact with the earth), holidays in coatings, changes in coating quality extending over large or small lengths of pipe, location of insulating joints, location of high resistance joints, contacts with other structures, etc.

Any discussions of this article not published above will appear in the June, 1959 issue

NACE TECHNICAL COMMITTEE REPORT

Observations on the Resistance of Natural Timbers to Marine Wood Borers

A Contribution to the Work of Group Committee T-9
On Marine Biological Deterioration,* by C. H. Edmondson**

Introduction

THERE is a marked difference in the degree of resistance of natural woody plants to the action of marine borers. Many woods are rapidly destroyed in sea water by ravages of molluscan and crustacean invaders, whereas others have varying degrees of immunity from these attacks.

The recognition that some natural woods have greater durability in sea water than others extends far back into history. There is evidence that the ancient Romans exercised great care in selecting for shipbuilding purposes, timbers which had a reputation for qualities of endurance when subjected to marine borer attacks.

It was not, however, until the twentieth century that the probable factors of wood responsible for its durability in sea water began to receive serious consideration. The exceptional qualities of the Demerara greenheart (Ocotea rodiaei), under marine conditions, were known in Europe long before its good points were recognized by American marine engineers. But in course of time, trials of this timber in the Americas gained for it an added reputation for usefulness in maritime construction and increased its popularity for such purposes. It also became known as a timber containing toxic substances (alkaloids) in its tissues of such potency as to destroy marine wood borers which attempted to infest it. It was the unexpected failure of this timber in some of the locks during the construction of the Panama Canal, and the substitution for it of another South American timber known as "manbarklak" (Eschweilera longipes) that opened up a new field of speculation. In those particular situations where greenheart had failed, manbarklak presented marked resistance to marine borers. On the disclosure by van Iterson[1] that this durable timber contained siliceous inclusions in its tissues instead of alkaloids, the opinion that silica might

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Abstract

The question of why certain timbers have resistance to marine borer attack is considered from the standpoint of the nature of the attack-repelling property. The "toxic substances" theory and "silica content" hypothesis are examined at great length. The role of tannin as a possible protective agent is discussed briefly. The degree of damage occurring to borers' teeth was thought to be of significance in studying the mechanism of corrosion resistance. Also of importance was a comparison of morphological variations found in shells recovered from poisonous woods with those found in siliceous woods.   6.6.11

be an important deterrent of borer attack received a powerful stimulus.

Gonggrijp also had observed that some siliceous timbers resisted Teredo and renewed his investigations in support of the silica hypothesis. In the account and conclusions of his work, Gonggrijp[2] records that among 814 timbers examined 181 contained silica in varying amounts. So convinced was this investigator in the efficiency of silica in sufficient amount, plus compactness of tissue of the wood, that he was led to declare that this combination "produces a much better protection against Teredo than all other known protective agencies for timber." As reported by van Iterson[1] the silica hypothesis was based upon the belief that the hard siliceous granules of the wood gradually wore away the delicate teeth of the cutting areas of the shell of the shipworm until a point was reached when the boring organism could no longer operate. This inference was supported by the observation that the teeth of saws were rapidly dulled in the processing of highly siliceous timbers.

Even before the investigations of Gonggrijp attention had been called to the presence of silica in forest timbers. Within the past 16 years several lists of woods of considerable size have appeared the object of which has been to contribute information regarding siliceous species. In 1942 Frison[3] listed over 700 African timbers, about 10 percent of which contained silica in varying amounts. Besson[4] in 1946 analyzed about
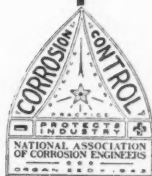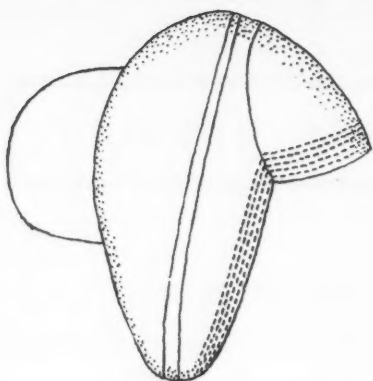
Figure 1—Valve of a typical *Teredo*.
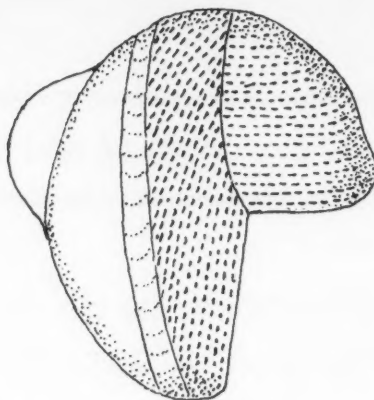
Figure 2—Shell recovered from Demerara greenheart.
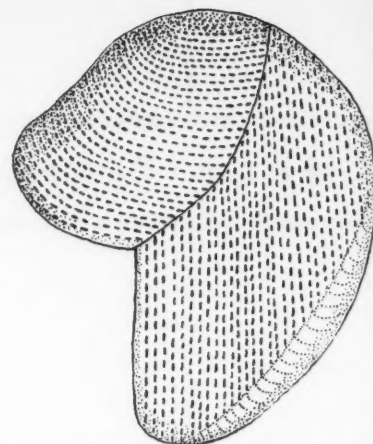
Figure 3—Shell recovered from *Syncarpia lauifolia* (Australian growth).

150 timbers from Africa, South America and Asia. Of these 24 species were rich in silica. A very comprehensive report by Amos and Dadswell[5] appeared in 1949 which listed 374 siliceous timbers from various sources.

Toxic Substances Theory

The two outstanding views of natural wood protection against marine borers persisting at the present time may be considered as (1) The toxic view, and (2) The siliceous view. The toxic view postulates that the wood contains poisonous elements of such potency that the borer larva may be destroyed on penetrating the surface or soon after. Defensive properties of even a highly toxic wood may vary greatly. Allowance must be made for differences in tolerence among borers as individuals or species, for a possible unequal distribution of the toxic elements, and for numerous factors of environment. Definite toxic substances have been determined in some timbers. Alkaloids in certain woods and more often in barks play a role of defense which can hardly be disputed when supported by experimental work and longstanding observation.

The Demerara greenheart with its recognized alkaloid content has a long record of usefulness in sea water and also, an occasional record of failure. Its failures are usually attributed to environments of low salinity where it is open to attack by those shipworms which are restricted to brackish water situations. This appears to be the reason for its behavior in the Panama Canal. This also was confirmed by Watson[6] at Brisbane, Australia, where in low salinity areas greenheart was riddled in 15 months, whereas in localities of near-ocean salinity the timber showed only minor surface damage over a period of several years.

During operations in Honolulu Harbor, samples of Demerara greenheart varied somewhat in reaction to marine borers. Attacks by shipworms, however, were never more than light to moderate, with a maximum penetration of about 35 mm, the greatest damage resulting from *Limnoria*. At the observation station in the harbor the water ranged slightly under ocean salinity. Here an Indonesian timber with recognized alkaloid contents, *Eusideroxylon zwageri*, proved to be much less susceptible to all forms of marine borers than did

Demerara greenheart. Repeated tests of lignumvitae *(Guaiacum officinale)* gave results ranging from apparent immunity to low resistance to *Teredo* over periods exceeding one year. Samples analyzed rated fairly heavy with alkaloids. Doubtless the varying response reflected differences in quantity of toxic elements in the wood. It is suspected that the marked resistance to marine borers shown by the barks of such trees as the Chinese *Litchi*, the *Araucarias* and the *Cinchona* is due to the alkaloids which analyses indicate they possess.

But alkaloids are not the only potential poisonous elements which appear to have a deterrent effect upon marine borers. The cypress pine of Australia, *Callitris glauca*, has remarkable lasting qualities in sea water, only a very few shipworms being capable of becoming established in its tissues over a period of years. It apparently is equally repugnant to *Limnoria*. Dadswell and Dadswell[7] attributed the general durability of the wood to a volatile acid (callitris acid) held in situ by resinous material. Johnson[8] reports the volatile acid to be protective against termites and a liquid acid present to be destructive of certain fungi. There is little doubt that the acid combination of this timber is potent enough to offer considerable resistance against marine borers as well as destructive agents of air and soil.

Some of the most powerful poisons in nature are distributed among shrubs and trees. Some of these apparently retain their toxic properties for some time after submergence in sea water. Under such conditions others quickly lose their poisonous character and rapidly deteriorate by reason of marine borer attacks. In this latter category is a shrub, *Nerium oleander*, and a small tree, *Thevetia peruviana*, both of which grow luxuriantly in Hawaii and both of which are highly poisonous in their entirety (leaves, fruit, bark and woody tissue). The toxic properties respectively known as oleandrin and thevetin apparently are glucosides, digitalis-like in principle and rapidly dissipated by the leeching action of sea water. Seasoned blocks of both species respond in contact with marine borers as non-toxic, non-resistant woods. The bark is slightly more resistant than the wood, and green sections are less susceptible than seasoned ones. Moderate to heavy attacks by shipworms occur within a period of three months.

These features are characteristic of a non-resistant wood.

Apparently to satisfy a toxic hypothesis of wood protection in sea water the poisonous elements present must be sufficiently potent and of lasting character, which specifications will always be tempered by factors of environment. The known forest timbers which meet these qualifications appear to be comparatively few.

Silica Content Theory

To explain the resistance of other woods in which no toxic elements were detected the silica hypothesis was developed. Imposing lists of timbers stressing the silica content of species have been useful starting points for further investigations. As this theory gained ground the amount of silica deposited in the wood naturally became an important consideration. Dutch investigators concluded a silica content of 0.50 percent to be an estimated minimum amount for appreciable protection of a timber against marine borers.

It soon became evident, however, that it was not enough to know that a certain timber possessed a silica content of 0.50 percent or more. There was no assurance that wood possessing silica, even in considerable amounts, would stand up well against attacks by marine borers. Gonggrijp was well aware of this when he stipulated a degree of compactness of tissue of the wood in addition to the presence of silica in order to ensure protection. A notable example of high silica content and low resistance occurred in Hawaiian waters. The East Indian species of *Antidesma bunius* is grown sparingly in Hawaii. Chemical analysis of the wood gave the following results: silica, 1.42 percent; tannins, medium; alkaloids, none. The amount of silica present was well above the minimum suggested for protection, but repeated tests indicated a very low resistance against marine borers. The density of this wood, compared with that of other species of the genus rich in silica and high in resistance, was obviously of a low degree. However, hardness, density or compactness, in themselves cannot be depended upon for protection against marine borers. Some of the hardest woods known are rapidly destroyed in sea water. For prolonged durability something extra is essential and, in
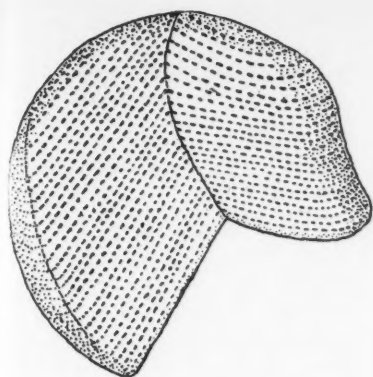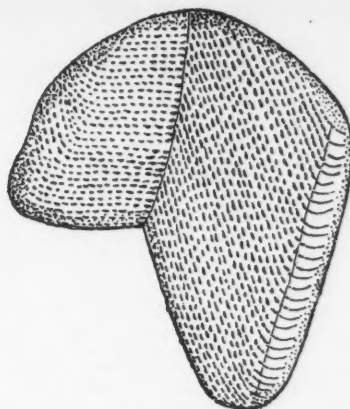
Figure 4—Shell recovered from *Eschweilera sagotiana.*

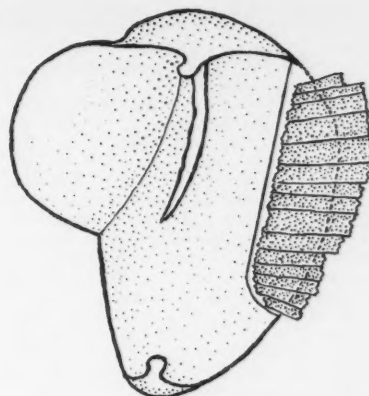Figure 5—Shell recovered from *Antidesma pulvinatum.*

Figure 6—Stenomorphic shell (remnant of posterior adductor muscle).

many instances, this appears to be silica in appreciable amounts.

By no means have all timbers rating high in silica been tested for their durability in sea water. Faith in the silica hypothesis, however, is sustained by a considerable number of siliceous woods, some of them with additional qualifications rendering them of potential or actual commercial value. Others have not entered the commercial lists because of scarcity, inaccessibility, manner of growth, cost of procuring or processing, etc. A few such timbers outstanding for their resistance to marine borers are as follows: *Dicorynia paraensis*, silica 2.92 percent; *Syncarpia laurifolia*, silica 1.24 percent; *Metrosideros petiolata* or *vera*, silica 0.89 percent; *Licania macrophylla*, silica 3.1 percent; *Viticipremma novae-pommerania*, silica 2.56 percent; *Eschweilera longipes*, silica 2.43 percent; *Antidesma pulvinatum*, silica 3.3 percent. The barks of some timbers also are noted for rich silica deposits and remarkable resistance to marine borers. In *Ficus indica* the wood, with only a trace of silica, offers no defense against shipworms but its bark, with a silica content of 2.30 percent, rates high in durability in sea water.

Presence of Tannins

However, no matter how much dependence is placed on known toxic elements in certain woods or in the high silica content of others, these factors do not cover the entire field of wood protection in sea water. Some woods and barks of trees indicate in their analyses only a trace of silica and no alkaloids at all, yet they present marked resistance to marine borers. In this connection mention may be made of the wood of *Vitex parviflora*, the barks of the China fir, *Cunninghamia lanceolata*; of the false olive, *Elaeodendron orientale*; of the mangrove, *Rhizophora mangle*; and of cork. In these medium to heavy amounts of tannins occur. It is not advisable, however, to place tannins high on the list of protective agents against marine borers as there are too many conflicting results. Many other barks and woods also present only heavy tannins but offer no appreciable resistance to marine borers.

An unpublished report by W. Y. Young, chemist of the Yard Testing Laboratory, Pearl Harbor, where most of the analyses referred to in this paper were made, has this to say: "The presence

or absence of tannins alone does not afford any positive indication as to the resistance of the sample [of wood] since many samples high in tannins are non-resistant and vice versa. In some cases, however, such as *Vitex parviflora*, resistance cannot be attributed to silica or alkaloid content and may be due to the high tannin content. The unpredictable results in the presence of tannins is possibly due to the variation in toxicity of specific tannins and also to their varying solubilities in sea water." The chemist also suggests that a combination of factors may in some instances contribute to the resistance of some woods. Or a combination of undetermined factors may not be impossible. The list of characteristic substances of barks and woods recorded by Record and Hess[9] is suggestive of numerous possible combinations which may be repugnant to the marine borer. It can only be said at the present time that the consideration of factors responsible for resistance to marine borers in many woods has not advanced beyond the point of speculation.

Damage to Borers' Teeth

Reverting to the silica hypothesis of wood protection in sea water, it may be said that the few criticisms of it that have appeared are not objections to the role that silica appears to play in checking the actions of the borers but questions relative to the mechanism of resistance. As previously mentioned, the abrasion process, or the wearing away of the teeth of the shell of the shipworm, was a prime consideration in the silica hypothesis. Van Iterson[1] was a champion of this mechanical mode of resistance and it has been generally accepted without much thought of evidence to support it.

Miller[10] pointed out that the teeth of the shell of *Teredo* are very brittle and are much more prone to be broken than to be worn away, and that broken teeth frequently do occur, probably as a result of contact with unusually hard areas of wood. This observer concluded, however, that action of the borer in ordinary pine or fir should not result in any appreciable wearing down of the teeth of the shell. No reference to silica was made by Miller but his observations might well imply that the teeth of the shell of *Teredo* boring in highly siliceous woods are more likely to be broken off

than worn away. In either case the silica hypothesis of resistance by mechanical means would be satisfied.

Amos and Dadswell,[11] without doubting the deterrent efficiency of silica, raised a question as to the validity of the abrasion process. These investigators suggested that since the silica inclusions were deposited in the wood under mild conditions of temperature and acidity they were not likely to be of such hardness as to destroy the teeth of the shell of the shipworm. Furthermore, it was pointed out that the silica granules were soluble in very dilute alkali (1 percent sodium carbonate) and, since they are held in the digestive tract for some time, considerable amounts may dissolve in mild alkaline conditions resulting in serious metabolic effects upon the organism.

These suggestions of Amos and Dadswell appear to be worthy of further biochemical consideration.

Morphological Variations in Shells

It is recognized that although natural woods may rate high in protective factors they are seldom completely immune to marine borers. A few hardy shipworms may occasionally become established and make some progress even in timbers of great reputed resistance. A valve of a typical *Teredo* is shown in Figure 1.

On examining the shells of *Teredo* occasionally lodged in highly protected woods the author's attention was soon directed toward the morphological variations which invariably occurred in shells recovered from siliceous timbers as compared with those from poisonous woods. Shells recovered from woods heavy with alkaloids or determined acids, as the Demerara greenheart and the cypress pine, were perfectly normal. The teredinids apparently perished without any mechanical obstructions which leave an impact upon the shell. A lethal poison applied internally would probably accomplish this (see Figure 2).

On the other hand, shells of *Teredo* from woods of high silica content, almost without exception, were seen to have assumed stenomorphic characters —somewhat deformed, thickened shells, greatly enlarged cutting areas and reduced or completely eliminated auricles. Specimens of shells recovered from *Syncarpia laurifolia* (Australia grown), from *Eschweilera sagotiana*, from *Antidesma pulvinatum* and others rating high in silica were typically stenomorphic

(see Figures 3, 4, 5.) It should be stated, however, that although stenomorphs appear with great regularity in highly siliceous timbers, they sometimes occur under other conditions.

The term "stenomorph" was introduced into the literature of shipworms by Bartsch[12] in 1923. This term, according to its author, covered stunted forms of shipworms brought about by crowded conditions, and might well be applied to other groups of organisms presenting corresponding abnormal features. In 1925 Clapp[13] concluded that stenomorphs were not caused by crowded conditions as they were often found in large pieces of wood, and that shipworms blocked from advancing, for any reason, may add cutting ridges to the shell although there is no further opportunity for activity.

The writer's observations support, in part, the views of both Bartsch and Clapp on the probable cause or causes of the formation of stenomorphs. There is little doubt that, at times, overcrowding may be responsible for the abnormal forms assumed by shells of shipworms. However, the writer frequently has recovered such shells from large sections of wood where a condition of crowding could not possibly have been a factor. More likely it is some character of the wood itself that discourages the progress of the shipworm. In an apparent attempt to overcome a difficult situation an increase in the number of cutting ridges in the shell takes place, often to the extent that nearly the entire external surface of the valves become close set with rows of denticles and, at the same time the auricular portion of the shell is eliminated. The disappearance of the auricle is a gradual progressive process. In specimens of *Teredo* penetrating *Antidesma pulvinatum* to a depth of 10 mm the reduction of the auricle may be about 50 percent; by the time specimens reach a depth of 25 mm

the elimination of the auricle is complete.

In the living shipworm the auricle of the shell is the seat of the posterior adductor muscle. As Miller[10] has shown this adductor muscle occupies almost the entire inner surface of the auricle and, in cross section, may be as much as 13 times that of the anterior adductor muscle. The powerful posterior adductor muscle is responsible for the outward movement of the anterior border of the valves of the shell during the cutting process; this action consisting of a lateral rocking movement of the valves with the alternate contraction and relaxation of the anterior and posterior adductor muscles. It can be assumed that with the gradual disappearance of the auricle there is a corresponding reduction of the posterior adductor muscle, until a point is reached when normal movements of the shell are no longer possible. In the stenomorph there is an appearance of a progressive expansion of the anterior portion of the shell where the cutting function is performed, at the expense of the thin, posterior area, the auricle. Whether a resorption process is actually taking place, resulting in a redistribution of material from one part of the shell to another, is unknown. However, there seems to be a very definite correlation between gain and loss of different portions of the stenomorphic shell. An examination of the inner surface of the valve of a stenomorph soon after the organism perished indicates the remnants of the posterior adductor muscle still attached to a vestige of the auricle (see Figure 6.)

Careful studies of the denticular surfaces of valves of shipworms recovered from siliceous timbers have convinced the writer that the abrasion view of the silica hypothesis needs further confirmation. He has been unable to detect the degree of wear and destruction of

denticles on the shells of stenomorph which apparently should be present to satisfy the supporters of that view. The suggestion here offered relative to the loss of muscular activity as a result of the shipworm's contact with severe conditions is not adverse to the silica hypothesis but presents another aspect of the possible direct effect of certain protective factors of natural timbers upon the marine borer.

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Laboratory and Field Methods for Quantitative Study Of Sulfide Corrosion Cracking*

By J. P. FRASER, G. G. ELDREDGE and R. S. TRESEDER

Introduction

A SINGLE cracking-type failure in a sour gas well could prove very serious, both from an economic standpoint and in terms of safety to personnel. This was recognized early in this investigation of sulfide corrosion cracking, and it made an early solution to the problem imperative. However, there were a large number of metallurgical and environmental variables to be studied. It became apparent that many individual tests would be needed and that simple but quantitative test methods were needed for use in both the laboratory and the field.

The need for quantitative methods should be emphasized. Early qualitative laboratory tests for sulfide corrosion cracking had indicated considerable variability in the data. In some tests, time to failure of replicate specimens was found to be variable;[1] in others, the number of specimens which failed in a given test period was found to be variable.[2,3] Similar statistical fluctuations are apparent in stress corrosion cracking tests used by others.[4]

The apparatus and test procedures described in this paper were developed as a result of the need for more quantitative test methods. Although developed for a specific application, there is reason to believe that these methods can be applied to many other stress corrosion problems. For purposes of the present discussion, sulfide corrosion cracking can be considered as merely a special case of stress corrosion cracking.

General Requirements for a Stress Corrosion Cracking Test Method

In order to obtain a maximum of useful information from stress corrosion cracking tests, the test method should meet the following general requirements:

1. **The apparatus size and design** should allow multiple testing to be done easily and at low cost.

2. **Method of loading** of specimens should be such that the load is known, is reproducible, and can be varied over a wide range. In addition, it is desirable that the nature of the applied stress (i.e., whether produced by constant deformation or constant load) be similar to that found in the practical system being investigated.

3. **The test environment** should be related closely to that found in practice.

4. **The information derived from the test** should be quantitative so that comparison can be made regarding the relative resistance to cracking of various materials or the relative severity of various environments. This is an inherently difficult problem with stress corrosion cracking because an individual test specimen either fails or does not fail. Furthermore, even in qualitative tests, it usually is found that duplicate tests do not yield the same results; some specimens may fail under conditions in which nominally similar specimens do not. This aspect of the general problem will be discussed in some detail before proceeding to a detailed description of the test apparatus and procedures.

The Problem of Obtaining a Quantitative Answer from a Stress Corrosion Test

If two or more alloys are susceptible to stress corrosion cracking in a given environment, it is often important to learn their relative susceptibilities. However, this is not a simple task, because stress corrosion cracking is basically a "go or no-go" phenomenon, that is, a specimen will either fail by cracking in a given test or not. In order to rank different alloys, it is necessary either to use some additional measure of damage or to measure the variable time involved, or to vary and control some causative or contributory factor.

For specimens which have been exposed for a given time but have not failed, additional measures of damage could include loss of strength or the number of cracks per unit area. However, these measures of damage have the same disadvantages as failure itself. Most specimens show either no damage at all or show cracking which would constitute failure in a practical sense.

Time could be measured either to first cracking or to failure or perhaps to both. It has merit in that, if test conditions are a reasonable reproduction of field conditions, the absence of failure in a long test period gives assurance that the test material could be used safely. The main difficulty from a test viewpoint lies in the long time period required to obtain an answer. Since one is concerned primarily with resistant materials, test periods of the order of months or years may be required. In addition to the obvious delay in obtaining answers in such tests, the large quantity of apparatus involved and the space required to house it, there is the experimental difficulty in laboratory tests of maintaining constant environmental conditions for long time periods.

Causative or contributory factors that can be varied include temperature, environmental composition, and stress. The effect of temperature can be analyzed in terms of activation energy for crack initiation or for crack propagation, depending on which is measured. This very useful technique has been described and demonstrated by Hoar and Hines.[5] However, it is doubtful that it would be easily applicable to the pres-

Abstract

Quantitative procedures for sulfide corrosion cracking tests, both in the laboratory and in the field, have been developed. The statistical techniques of probit analysis have been adapted for use with cracking test data so as to make optimum use of a minimum number of tests.

Analysis of the data from laboratory tests yields a number which is called the critical strain, S_c. This is the strain at which the probability of failure under the specific test conditions used is one-half. Very susceptible steels have low S_c values whereas non-susceptible steels have high S_c values. The critical strain is a function not only of the alloy tested but also of the test environment and procedure. It is lowered by addition of acids (especially organic acids such as acetic) and carbon dioxide.

Using alloys of varying S_c values, all tested at the same high strain, the relative severity of any given test environment (e.g., flow from a sour gas well) can be measured. Analysis of the data from field tests yields a severity rating, R_s, which is the critical strain of an alloy which would be expected to give 50 percent failures in test. High R_s values are associated with severe test environments and low R_s values with mild environments.

This general method may be adaptable to other stress corrosion systems, and thus provide a quantitative means of expressing susceptibility to attack or severity of an environment. 2.3.7

ent problem of determining the relative susceptibility to cracking of various materials. The experimental techniques required are quite laborious, and the values obtained cannot be translated directly to numerical quantities of interest to field applications.

The effect of environmental composition could be expressed, for example, as the pH required for cracking. However, it is difficult to control composition within close limits for long test periods. In addition, it may be of interest to study the effects of environmental composition, independent of the ranking of different alloys.

The approach of varying stress offers the most possibility for providing a quantitative answer of practical significance within a reasonable time period. For test periods of finite length, it is reasonable to believe that the threshold stress for stress corrosion cracking would vary among materials in a manner related to their relative susceptibility to attack. The key point here is the fixed time period, as many investigators have agreed that a real threshold stress does not exist for stress corrosion cracking; at low stress levels the time to failure merely becomes exceedingly long. From the experimental viewpoint, determination of an apparent short-term threshold stress is difficult, because the statistics of failure probability at this extreme condition may necessitate a great number of tests.

An alternative to determining a threshold stress would be to determine the

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stress (or strain) at which the probability of failure is one-half. This is the approach used in the method described in this paper. This is a more simple approach statistically and is just as useful for comparing the relative susceptibility to cracking of two or more alloys. As in the case of measuring the "threshold stress" for cracking, this involves testing

within a definite time period; for practical reasons this should be no longer than several weeks.

Critical Strain Concept

As indicated above, the present test method obtains a quantitative answer by determining the degree of loading for a specific alloy at which the probability of cracking failure with the test period is one-half. The number obtained is called the "critical strain" and is characteristic for the particular alloy tested. High values are associated with high resistance to cracking, and vice-versa.

The strain reported is the maximum strain in the outer fibers of the beam specimens which were used and is calculated from the measured maximum deflection by means of the simple beam formula. It is a nominal value as no allowance is made for the stress raisers present. It is preferred to use strain rather than stress because the loading necessary to produce failure is such that the yield strength is exceeded in many instances.

The problem of determining the critical strain is analogous to that found by toxicologists in determining a lethal dose. A statistical technique used by the toxicologists called "probit analysis"[6] has been adapted to the analysis of sulfide corrosion cracking test data. The test procedure consists essentially of exposing a number of specimens (usually about twelve) at each of several different strain levels, all in the same environment. The test strains are chosen as close as possible to the estimated critical strain so as to obtain maximum information from each of the limited number of test specimens. The precision of the critical strain measurement depends on this choice of strain and the number of specimens tested. Using about twelve specimens, the standard error of the determined critical strain has been found to be about 0.1×10^{-3} inch/inch in one particular test environment.

Laboratory and Field Test Methods

It was found expedient in laboratory tests to compromise several of the general test requirement set forth above. In each case, the test variables were studied in sufficient detail to understand the effects of the compromises made. The compromises made are as follows:

1. Loading. Oil well tubing in service is under constant load. However, constant deformation testing is much simpler to use than constant load testing. In addition, the apparatus can be made much more rugged and compact. For these reasons, most tests have been made using constant deformation, although a few have been made at constant load.

2. Test conditions. In order to obtain failures of relatively resistant materials in a reasonably short period of time, it is necessary to increase the severity of the test conditions. This can be done by increasing the severity of the test environment or by testing at high stress levels. Here both approaches were used. The severity of the hydrogen sulfide-water system was increased by addition of acetic acid, and the stress conditions were made severe by incorporating stress raisers in the specimens and, in some instances, by loading beyond the yield strength. To translate test results to practice involves the assumption that the relative order of resistance to cracking of various materials will not change as one decreases the severity of the environment providing the essential corrosive nature is not changed.

Experience to date has indicated this assumption to be correct in the case of sulfide corrosion cracking. It should be noted that the severity of the test might also be increased by changing the test temperature. This approach has been used in stress corrosion cracking studies made by others.

The detailed procedures and description of apparatus used are given in Appendix A.

Effect of Test Variables

With the development of a precise means of measuring resistance to cracking, it has become possible to evaluate quantitatively the effects of test variables such as stress raisers, surface finish, organic acids, and test atmosphere.

Stress Raisers

The effect of stress raisers is, of course, to lower the apparent strain required for failure. As shown in Table 1, use of two No. 70 holes on the transverse centerline (present standard specimen) divides the critical strain by a factor of about 2.4, which is approximately the stress concentration factor introduced by the holes.[3] Stress raisers were originally used in this investigation in order to introduce multiaxial loading, because of the widely-held opinion that complex loading conditions favor stress corrosion cracking.[4] However, it appears from the data that the effects of stress raisers are simply to raise the local stress (strain).

After yielding of the metal starts, the effect of the stress raiser holes becomes more difficult to define inasmuch as: (1) the maximum outer fiber strain is not known, and (2) the effect of stress concentrators becomes progressively smaller with increasing plastic strain. It is possible that the effect of the holes actually is one of total local strain, in which case the stress raiser holes may continue to have a "stress concentration" effect above the point of initial yielding by virtue of increasing local strain, probably by a factor of about twice that in a plane-surfaced specimen. In any event, the stress raiser holes used are known to lower appreciably the nominal outer fiber strain needed for failure in the standard laboratory test.

Surface Finish

Surface finish can be an important test variable because the strains remaining in the surface layers from the machining operations add to the applied strain. For example, surface grinding by machine introduced residual tensile strains on the order of 0.3×10^{-3} inch/inch, judging by the fact that cracks appeared on the compression side of a very susceptible alloy in laboratory sulfide corrosion cracking tests. If the critical strain for cracking is low, residual strains may be an appreciable fraction of the S_c value.

Environment

Addition of acetic acid to the solution lowers the S_c value of a given steel as shown in Table 2. The effect is not one of initial pH, because the critical strain for cracking is lower in acetic acid than in hydrochloric acid of the same initial pH (see Table 2). However, the total available hydrogen ion from hydrochloric acid is much less than that from acetic acid at the same initial pH, since acetic acid is weakly ionized. For this reason, the pH of the hydrochloric acid solution probably rises
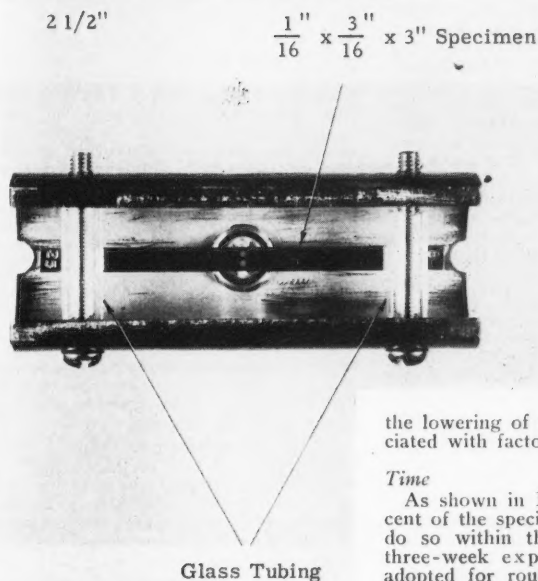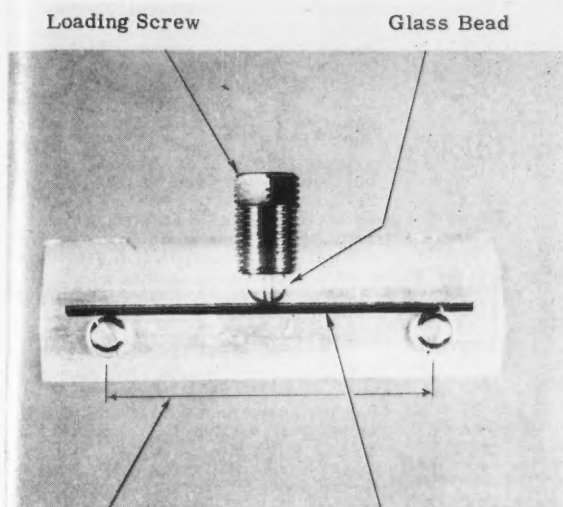
Loading Screw   Glass Bead

2 1/2"

$\frac{1}{16}$" x $\frac{3}{16}$" x 3" Specimen

Glass Tubing

Figure 1—Laboratory test holder. Top: phantom view of assembled holder and specimen; bottom: view of holder from bottom.

Loading Screw
Glass Bead
1/16" x 3/16" x 2 5/8" Specimen
Glass Support Rods on 2 1/2" Centers

Figure 2—Stress corrosion cracking field test holder.

1/16" x 3/16" x 3" Specimen   2 1/2"
End Support Bolts
Loading Screw
Holes for Set Screws of Clamping Device on Loading Jig
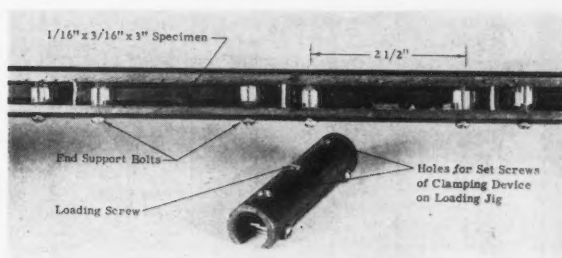
Figure 3—Test holder for use in small lines.

Clamping Device for Positioning Specimen and Holder
Spring-Loaded Set Screws
Extension of Dial Gage Point
Dial Gage

Figure 4—Jig for measuring deflection of specimen while loading.

more rapidly than the acetic solution as corrosion proceeds, and this could account for the difference in behavior of the two acids. A second possible explanation for the difference in behavior lies in the physical character of the scale formed. In distilled water or very dilute hydrochloric acid plus hydrogen sulfide, the corrosion scale is soft and easily removed; in acetic acid plus hydrogen sulfide it is hard and adherent although it apparently does not provide protection from corrosion. A third possible explanation for the difference in behavior is that acetate ion may promote entry of hydrogen into steel more effectively than does chloride ion. This explanation presumes that occluded hydrogen is involved in the mechanism of sulfide corrosion cracking.[2]

Use of a mixture of carbon dioxide and hydrogen sulfide instead of hydrogen sulfide as the test atmosphere lowers the S_c value of a given steel as shown in Table 2. As with acetic acid, the lowering of S_c values may be associated with factors other than pH.

Time

As shown in Figure 7, about 80 percent of the specimens which fail in test do so within the first three days. A three-week exposure time has been adopted for routine laboratory testing, because 98.5 percent of all specimens which fail do so in this time.

Constant Load

One possible reason that no failures occur after the first few days in test is that a multitude of very shallow cracks may form on the tension side of the specimen within a few days, thereby relieving the applied stress. If constant load testing were used rather than constant deflection, no such stress relief would be possible, and the time to failure would be inversely related to the strain. At strains much below the critical strain, the time to failure would become very long. A limited number of tests have been made with an N-80 steel having $S_c = 3.3$ which indicates that this is true (see Table 3). One specimen of this steel failed at a nominal applied strain of 1.5×10^{-3} inch/inch. In the standard laboratory test, no failures would be expected below an applied strain of 2.2×10^{-3} inch/inch (three standard deviations below S_c, see Table 5).

Field Test Method

It is important to be able to determine the severity of a field environment (e.g., gas well flow stream) relative to other environments. Also, if an inhibitor is used to prevent cracking, it is essential to have some method of measuring its effectiveness. The relative severity of a given environment may be characterized in two ways:
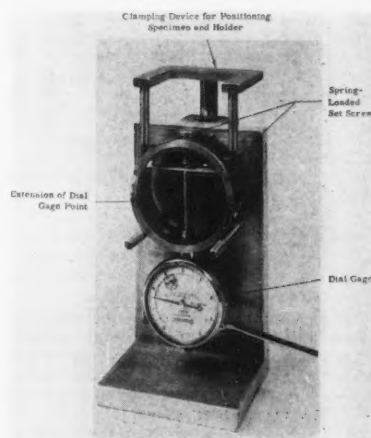
1. Determine the S_c of a given alloy by exposing specimens at various loads

Figure 5—Test specimen.

Figure 6—Work sheet for use in computing S_c values by means of probit analysis.

in the unknown environment and compare the new value with the S_c determined in the standard laboratory environment (e.g., see Table 2).

2. Expose alloys having different S_c values, all at the same nominal strain, in order to find that alloy which, when exposed at a given high strain, has a 50 percent failure probability in the new environment.

In practice, the second method is the easier.

The procedure consists of exposing a wide variety of alloys having different S_c values to the unknown environment at the same strain level (4×10^{-3} inch/inch). In general, those alloys with low S_c will fail and those with high S_c will not fail in test. By use of probit analysis, it is possible to calculate the S_c value of that alloy which would have a 50 percent failure probability. The relative severity of the environment (R_s) then is given by the S_c value of this alloy. Detailed procedures for field testing and analysis of test results are given in Appendix

A. Typical flowline test data are shown in Table 4. It should be noted that a high R_s value indicates a relatively severe environment, whereas a low R_s value indicates a mild environment. The standard laboratory test environment (0.5 percent acetic acid saturated with H_2S at room temperature) has $R_s = 4.0$, by definition.

Empirical Constants

Calculation of the critical strain of an alloy, S_c, or the relative severity of a test environment, R_s, involves use of an empirical constant. This constant is equivalent to the standard deviation of the test data. The constant used here is the reciprocal of that used by toxicologists who originally developed the statistical technique of probit analysis.

As shown in Table 5, the value of the empirical constant used to determine the critical strain varies slightly with the alloy being tested. It is presumed that the empirical constant used to determine the relative severity of a test environment will vary similarly with the

environment. Fortunately, S_c and R_s values are relatively insensitive to changes in the empirical constant. For general purpose testing, the constant used to calculate the critical strain can be taken as 0.29 for all alloys, where the applied strain is expressed in 0.001 inch/inch units.

Insufficient data are available to permit comparing values of the standard deviation for different test environments. From the limited field test data available, such as that in Table 4, the average value of the empirical constant (i.e., standard deviation) is about 0.78. It is assumed that this value will apply to other environments.

Effect of Metallurgical Variables

Development of a precise means of measuring resistance to cracking also has permitted quantitative study of the influence of metallurgical variables. Such a study is described in a paper by Fraser and Eldredge.[9] Their paper discusses the influence of composition, mechanical properties, and heat treatment on the susceptibility of low alloy steels to sulfide corrosion cracking. In general, high manganese, molybdenum, and nickel content are associated with low S_c values, whereas high carbon content is associated with high S_c values. High strength and hardness are associated with low S_c values and high ductility with high S_c values. The manufacturing process does not appear to influence resistance to cracking very strongly, but the critical strain for cracking of normalized molybdenum-bearing N-80 steels may be raised markedly by tempering for one-half hour at about 1100 F, without excessive loss of strength.

Summary

1. Test apparatus and procedures have been developed for studying sulfide corrosion cracking which may have general applications in the broader field of stress corrosion cracking.

2. By use of the procedure given, a quantitative means of expressing the relative susceptibility to cracking of a specific alloy in a specific environment may be obtained. The characteristic number determined for a specific alloy is the "critical strain," i.e., the strain at which the probability of failure under specified test conditions is one-half. It is calculated by the statistical technique of probit analysis.

3. By a modification of the method it is possible to obtain a number, the "severity rating," by which the relative severity of various environments can be measured.

4. The influence of a number of test variables such as stress raisers, composition of test solution, time of exposure, and type of loading on the "critical strain" determination has been studied.

Acknowledgment

The authors acknowledge the cooperation of their colleagues in Shell Development Company, especially the guidance of Dr. A. Wachter, and the suggestions and constructive comments of T. M. Swanson.

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APPENDIX A—TEST METHOD

Method Summary

In laboratory tests, specimens were machined from oil well tubing, casing, etc., stressed as simple beams to various nominal maximum outer fiber strains, and exposed to an aqueous hydrogen sulfide bearing solution. In general, the test strains used were as close as possible to the critical strain for cracking. Successive approximations to the critical strain were calculated after testing each new specimen, about twelve specimens usually being required to give a reliable estimate of the critical strain.

Specimen Holders

For laboratory tests, holders of the type shown in Figure 1 were used. These were constructed of 18-8 stainless steel (AISI Type 302, 304, or 316 preferred). Glass spacers were used to insulate the test specimens from the holder. These holders were mounted in units of four, using the ends of the specimen support screw to fasten the holder to the strap.

For field tests, holders of the type shown in Figure 2 were used for larger than 3.15-inch ID pipe and of the type

shown in Figure 3 for 1.25 to 3.15-inch ID pipe. These holders have been made of both carbon steel and of 18-8 stainless steel.

Test Vessels

For laboratory tests, use was made of 63 x 450 mm (approximately 1200 ml) hydrometer cylinders with glazed flanges at the top*, in which four specimens could be tested simultaneously. A rubber stopper closure was used which carried about 8 mm OD gas inlet and outlet tubes. The inlet tube extended to within 25 mm of the bottom of the cylinder, and the lower end was sealed with an 8 mm OD fritted glass cylinder with uniformly spaced pores of 170 to 220μ.**

For flowline field tests, a four-foot long flanged test section was used as the flowline. Such a section accommodates two assemblies of the type shown in Figure 2. If the test section has greater internal diameter than 4 inches, an 8-mesh steel screen should be wrapped around the whole test specimen assembly to prevent broken specimens from being washed down the line. Where it is desirable to use a test section smaller than 3.15-inch ID, this section should be no smaller than 1.25-inch ID and should be at least two inches longer than the specimen holder shown in Figure 3. Orifice plates may be used to keep the specimen assemblies from being pushed downstream by the flow stream.

Deflection Gage

A dial gage, graduated in 0.0001-inch divisions, was used to measure the deflection of the center of the test specimens, as shown in Figure 4.

Test Solutions

Laboratory test solutions were prepared fresh as needed from distilled water which had been vigorously purged with nitrogen gas for one-half

* Cylinder such as Kimble Catalog No. 20065.
** Corning Gas Dispersion Tubes 12EC, Catalog No. 39533 conform to these requirements.

hour. Care was taken to avoid contamination with air, since oxygen is known to accelerate corrosion by acidic hydrogen sulfide solutions.

The standard laboratory test solution consisted of 5.0 ml glacial acetic acid dissolved in 1000 ± 10 ml of air-free distilled water. This solution was used for routine comparison of different steels and for studying the effects of inhibitors. Other test solutions were made up in similar fashion in order to study environmental variables such as organic acid content and the presence of salts.

Test Specimens

Test specimens were machined as shown in Figure 5 from pipe to be tested. Care was taken to avoid overheating during preparation. Specimens were 2.65 ± 0.05-inch long for field test specimens but could be longer for specimens tested in the laboratory. Two No. 70 holes were drilled on the transverse centerline of each specimen to act as stress raisers. These stress raisers also served to introduce complex loading conditions, which are thought by some to be conducive to stress corrosion cracking.[7]

Identifying marks were stamped only on one side of each specimen and only within ½-inch of either end.

The final surface finish was produced by No. 180 grit abrasive, using a dry belt grinder. Specimens were hand held and were carefully abraded to remove all evidence of previous machining. The final scratches were parallel to the length of the specimen. All edges were carefully rounded to remove nicks and burrs. The final thickness was measured with micrometer calipers to the nearest 0.0001-inch.

It should be noted that a surface grinder can introduce large residual stresses. If a surface grinder was used in machining the specimens, the last two passes on either side of the specimen removed no more than 0.0005-inch of metal. The disturbed layer on the surface was removed by carefully abrading as above.

After machining and abrading the surface, the specimens were cleaned all over with a clean rubber eraser, rinsed in acetone, and dried. The specimens were handled with stainless steel forceps after cleaning and were stored with a desiccant until ready for use.

Loading Test Specimens

After choosing the nominal maximum outer fiber strain to be used, the corresponding deflection of the middle of the specimen was calculated by means of the following equation:

TABLE 1—Effect of Stress Raisers on Resistance to Cracking

Alloy	Alloy Ref. No.	Stress Raisers	No. Specimens Tested	Cracking Results, S_c	Ratio
5 Cr	7-101	No	10	2.2	
		Yes	24	0.8	2.8
9 Cr	7-103	No	10	1.2	
		Yes	20	0.6	2.0
9 Ni	7-106	No	14	1.6	
		Yes	31	0.7	2.3
				Average =	2.4

Conditions: Standard laboratory test except as noted above. Specimens tested either with: (a) no stress raiser holes, or (b) with two No. 70 holes on transverse centerline.

TABLE 2—Effect of Test Solution Composition on Resistance to Cracking

Alloy	Alloy Ref. No.	Solution		Atmosphere	pH	No. Specimens	Cracking Results, S_c
9 Ni	7-106	Dist.	H_2O	H_2S	4.02	12	2.9
		0.01%	HAc	H_2S	3.64	8	1.6
		0.1%	HAc	H_2S	3.16	12	1.2
		0.5%	HAc	H_2S	2.93	31	0.7
		Dist.	H_2O	$H_2S + CO_2$	3.63	8	1.3
		0.0037%	HCl	H_2S	2.93	8	1.3
9 Ni	7-117	0.1%	HAc	H_2S	3.16	12	2.1
		0.5%	HAc	H_2S	2.93	24	1.1
N-80	7-108	0.1%	HAc	H_2S	3.16	12	3.8
		0.5%	HAc	H_2S	2.93	42	2.8

Conditions: Standard laboratory test except for solution composition or atmosphere as shown.

TABLE 3—Sulfide Corrosion Cracking at Constant Load

Nominal Maximum Fiber Strain, Inch/Inch x 10^3*	Time to Visible Cracking, Days**
2.0	10
1.5	>216
1.5	216

Conditions: Standard laboratory test except as noted below.
Specimens of N-80 steel (Alloy Reference No. X-218).
Specimens held in spring-loaded stressing jig.
* Note: Critical strain of Alloy Reference No. X-218 in standard laboratory test is $S_c = 3.3$, based on 47 test specimens.
** > indicates no cracking within test period.

DATA TAKEN FROM 200 SPECIMENS WHICH
FAILED IN THE STANDARD LABORATORY TEST.

NOTE: IN ALL CASES, THE ACTUAL TIME TO FAILURE
WAS LESS THAN SHOWN, SINCE EXAMINATION
OF SPECIMENS IN TEST WAS INTERMITTENT.

Figure 7—Time to failure.

TABLE 4—Sulfide Corrosion Cracking Field Test

Alloy	Alloy Ref. No.	Cracking Test Results*	S₀**
9 Ni............	X-1314BH	XXX	0.?
9 Ni............	X-1205	XXX	0.?
SAE 4340.......	7-98	XXX	0.?
9 Ni............	7-97	XX	0.9
5 Ni............	7-117	000	1.1
P-110..........	X-1351C	XX	1.4
9 Cr, 1 Mo......	7-156	XXX	1.8
N-80 (normalized)	X-1243	XX0	2.0
N-80 (normalized)	7-108	X0	2.8
N-80 (warm worked)........	X-1351A	00	3.0
N-80 (cold drawn)	X-1356-4	00	3.1
J-55............	7-140	00	3.7
N-80 (quenched and tempered)..	X-1334B	00	4.0

Conditions: Standard field test procedure.
Specimens exposed to water saturated with field gas containing 35 percent v H_2S + 10 percent CO_2 at 500 psig.
  Apparent R_s based on all specimens = 1.5.
  Apparent R_s leaving out 5 Ni (7-117) = 1.7.
  * X = specimen failed in test; 0 = specimen did not fail.
  ** As determined in standard laboratory test (0.5 percent acetic acid saturated with H_2S).

Deflection of middle of specimen,

$$\text{inches} = \frac{\varepsilon L^2}{6t}$$

where ε = nominal outer fiber strain, in./in.,
  L = distance between end supports, inches, and
  t = thickness of specimen, inches.

This formula assumes that the specimen behaves elastically. With soft materials, the nominal outer fiber strain to cause cracking may be such that the yield strength is exceeded. In this case, the reported nominal outer fiber strain is not the true outer fiber strain in the specimen. However, if the so-called nominal outer fiber strain is regarded as a measure of the deflection, there should be no confusion.

Identifying marks on the test specimens were always placed on the compression (concave) side of the specimen or were outside the end supports.

Laboratory Testing

After straining, the specimens were inserted in the test solution, and the rubber stopper carrying gas inlet and outlet tubes was wired in place. The solution was then saturated for one-half hour with the test atmosphere, usually cylinder hydrogen sulfide. The solution was resaturated daily by passing the test gas through for about one-half hour. A rubber tube was used to connect the inlet and outlet tubes when gas was not flowing through the test solution, thus sealing it off from the atmosphere.

Specimens were observed daily through the walls of the test vessel to determine which had failed. At the end of the test period (usually three weeks), specimens were removed from the solution and the individual test holders and examined for failure. At this stage, specimens were bent slightly to see if there was any incipient cracking. If a specimen contained any macroscopic cracks, whether or not they had propagated completely through the specimen, it was considered to have failed in test.

Typical Laboratory Test Program

It was generally found necessary to test at least eight, and usually about twelve, specimens of a given alloy at a variety of outer fiber strains in order to determine the critical strain for cracking in one environment. A typical procedure is as follows:

(a) One specimen was tested at the assumed critical strain.

(b) After three days, the specimen was observed for failure. If it had failed, a second specimen was tested at 0.5×10^{-3} inch/inch lower strain. If it had survived, the second specimen was tested at 0.5×10^{-3} inch/inch higher strain.

(c) Testing was continued until one specimen had survived (or failed). The next specimen was tested at a strain halfway between the last two. After testing this specimen, a tentative value of the critical strain was computed, using the alternative scoring method given below.

(d) The next four specimens were tested at strain increments of 0.1×10^{-3} inch/inch, the computed tentative value of the critical strain falling in the middle of the strain range covered.

(e) A new estimate of the critical strain was computed according to the alternative scoring method.

(f) The next four specimens were tested at strain increments of 0.05×10^{-3} inch/inch, the new computed critical strain value falling in the middle of the strain range covered.

(g) The best estimate of the critical strain was computed by means of probit analysis (see section entitled "Statistical Analysis of Results," below).

Field Tests

All specimens were strained to a nominal outer fiber strain of 4×10^{-3} inch/inch. After the specimens were strained they were inserted in the flowline or test vessel as soon as possible or were stored with a desiccant until ready for use.

At the end of the test period (usually two weeks), the specimens were removed from the flowline or test vessel, rinsed with acetone, removed from the holders, and inspected for failures.

In general, field testing involved a large number of alloys having widely varying critical strains for cracking as determined by the standard laboratory test. Some specimens were used to evaluate the environment. Other specimens of structural or tubular goods steel were used to determine whether the proposed materials of construction would serve satisfactorily in the environment.

Statistical Analysis of Results

The results of laboratory tests were scored by means of the following procedure, based on the statistical technique of probit analysis.[6] This procedure makes maximum use of the available data and will give the most reliable results.

Critical strain, inch/inch × 10³ =

$$S_c = S_o + B \frac{\Sigma TZ/E}{\Sigma Z^2/PQ}$$

where S_o = assumed value of the critical strain for the purposes of computation, inch/inch × 10³.

  B = 0.35 for API steels (based on 1282 tests).
   = 0.21 for alloy steels (based on 389 tests).
   = 0.29 for routine general purpose testing (based on 1671 tests).

  T = test result (T = +1 for surviving specimen and T = −1 for failed specimen).

$$Z = \frac{1}{\sqrt{2\pi}} e^{-D^2/2B^2} =$$

  ordinate of the normal probability curve for t = D/B.

  where D = ε − S_o, ε being the nominal maximum outer fiber strain of a given test specimen, inch/inch × 10³.

  E = P if specimen cracked in test.
   = Q if specimen survived test period.

$$P = \int_{-\infty}^{D/B} \frac{1}{\sqrt{2\pi}} e^{-x^2/2} =$$

area under the normal probability curve from $t = -\infty$ to $t = D/B$.

where x is a dummy variable

$$Q = 1 - P$$

A tabular form used in computing S_e values from experimental data is shown in Figure 6. However, when treating more than about 25 or 30 alloy samples, it was found convenient to use machine computation.

An **alternative scoring method** used is given below. This method is probably less precise than the method of probit analysis and is not worked out in theory, but is useful for predicting the critical strain as a guide for further testing. The critical strain is calculated by means of the following equation:

$$S_e = \frac{\Sigma\varepsilon + B'\Sigma T}{n}$$

where ε = nominal maximum outer fiber strain of a given test specimen, inch/inch $\times 10^3$.

B' = empirical constant (0.7).

T = test result ($T = +1$ for surviving specimen and $T = -1$ for failed specimen).

n = total number of test specimens used in the computation.

When using this method, it is necessary to discard all data more than $\pm 0.7 \times 10^{-3}$ inch/inch from the critical strain value.

The results of **field tests** were scored by means of the following procedure, based on the technique of probit analysis:

Severity rating, $R_s = R_o + K \dfrac{\Sigma TZ/E}{\Sigma Z^2/PQ}$

where R_o = assumed value of the severity rating for the purposes of computation, in S_e units (inch/inch $\times 10^3$).

$K = 0.78$, based on 170 tests.

T = test result ($T = -1$ for surviving specimen and $T = +1$ for failed specimen).

$Z = \dfrac{1}{\sqrt{2\pi}} e^{-D^2/2K^2} =$ ordinate of the normal probability curve for $t = D/K$.

where $D = S_e - R_o$

TABLE 5—Standard Deviation of Sulfide Corrosion Cracking Test Data

Class of Steel	No. Samples Within Class	No. Specimens Tested	B, in Same Units as S_c
N–80, molybdenum bearing	37	640	0.36
N–80, cold drawn and warm worked	13	190	0.23
N–80, normalized and tempered	12	135	0.36
N–80 and P–110, quenched and tempered	10	155	0.31
J–55	7	162	1.08
All N, J, and P steels	79	1282	0.35
Nickel steels	7	145	0.20
Chromium steels	11	161	0.22
SAE 4340 steels	5	83	0.18
All alloy steels	23	389	0.21

Conditions: When determining the critical strain, S_c, of an alloy by means of probit analysis, it is necessary to use an empirical constant, B. This constant is the standard deviation of the test data, and the value of B can be computed as a by-product of the critical strain calculation. The values of the standard deviation shown in the above table are the weighted average values of B for a number of alloys of similar composition.

$E = P$ if specimen cracked in test.

$= Q$ if specimen survived test period.

$$P = \int_{-\infty}^{D/K} \frac{1}{\sqrt{2\pi}} e^{-x^2/2} =$$

area under the normal probability curve from $t = -\infty$ to $t = D/K$.

where x is a dummy variable

$$Q = 1 - P$$

The tabular form shown in Figure 6 was used when computing R_s values from experimental data, inasmuch as the steps are completely analogous to those used for computing S_e values.

An alternative scoring method used occasionally is given below. It is useful for predicting the severity rating for further testing but is less precise than the method of probit analysis. The severity rating is calculated by means of the following equation:

$$R_s = \frac{\Sigma S_c + K'\Sigma T}{n}$$

where S_c = critical strain of given alloy tested, as determined in the standard laboratory test, inch/inch $\times 10^3$.

K' = empirical constant (1.0).

T = test result ($T = -1$ for surviving specimens, and $T = +1$ for failed specimens).

n = total number of test specimens used in this computation.

When using this method, it is necessary to discard all data which are more than ± 1.0 S_e units from the severity rating value.

DISCUSSION

Questions by Joe Chittum, Whittier, California:

1. What method was used for introducing the stress raiser in the stressed specimens?

2. Isn't it necessary to place the holes in the center of the specimens?

3. Isn't it more difficult to reproduce two holes than one hole?

Replies by J. P. Fraser:

1. The stress raisers in our specimens consist of two No. 70 drilled holes. During drilling, the test specimen is held in a small jig to aid in locating the holes.

2. The holes are placed in the center of the test span. We do not consider the placement to be particularly critical. Hand placement and visual alignment have been used in all our tests, and we believe it likely that the stress raiser holes were within 0.02 inch of the center of the span in any test.

3. It is, of course, more difficult to reproduce two holes than one hole. However, we feel that the reproducibility of our stress raiser holes is on the same order of magnitude as our accuracy of loading, thickness measurement, and positioning. The rather small estimated error in measured S_e values suggests that the over-all errors in our test method are fairly small.

Any discussions of this article not published above will appear in the June, 1959 issue

Influence of Metallurgical Variables On Resistance of Steels to Sulfide Corrosion Cracking*

By J. P. FRASER* and G. G. ELDREDGE*

Introduction

SOUR GAS condensate production was discovered in Canada in the late 1940's. From previous experience with sour oil production and sweet gas-condensate production, it was recognized that the new sour gas wells would be corrosive. Accordingly, considerable care was used in selecting the materials of construction to be used in these wells. Good service experience had been reported for nickel-steel sucker rods in sour oil wells and also had been reported for 5 percent and 9 percent nickel steels in corrosive sweet gas condensate service. Extrapolating from this experience, 9 percent nickel steel tubing was installed in a sour gas-condensate well in the Pincher Creek Field, Alberta, Canada[1]. The result: the tubing failed by transverse cracking within six days.

Other failures of oil field equipment items have been recorded.[2,3] Some have occurred with high alloy steel such as 9 percent nickel and 12 percent chromium steels and others with high strength low alloy steels, notably those used in wire lines and bourdon tubes. A limited number of failures have occurred with API grade N-80 steel tubing. Failures have occurred in both sour gas and sour oil well service. The general phenomenon of cracking-type failures in hydrogen sulfide service has come to be known as "sulfide corrosion cracking."

None of the equipment failures to date has resulted in loss of a well or loss of life. Nevertheless, the hazards involved in a tubing failure in a deep, high-pressure, sour gas or oil well are great. These hazards have emphasized the need for a better understanding of the influence on susceptibility to sulfide corrosion cracking of chemical composition and mechanical properties of commercially-available steels, so that intelligent choice may be made of failure-resistant tubular goods.

Two broad conclusions can be drawn from the failure experience mentioned above: (1) hydrogen sulfide bearing fluids can produce rapid cracking-type failures of stressed steel, and (2) high-strength and high-alloy steels are particularly prone to such failures. These conclusions from field experience have been supported and made more detailed by several laboratory and field investigations.[4,5,6] The test procedures used in the past were largely qualitative, as were the conclusions which were drawn from them. Nevertheless, they were sufficiently quantitative to show that steels which are nominally the same in chemical composition and mechanical properties (e.g., API grade N-80 steel) may vary widely in susceptibility to cracking.

Recently, more quantitative test procedures[7] have been devised. These have been used to test a large number of low alloy steels of known composition and

mechanical properties for susceptibility to sulfide corrosion cracking. This paper presents and discusses the results of these tests.

A summary of the metallurgical properties of the alloys tested is given in Table 1. Particular emphasis has been placed on steels which are used for oil well tubing and casing, and the object of these tests has been to gain better insight into the influence of metallurgical variables on susceptibility to cracking.

After accumulating as much data as possible on each steel, a statistical analysis was made to determine the metallurgical variables that influence resistance to cracking. This analysis included several parts: (a) comparison of the different classes of steel (J-55, N-80, and P-110), (b) comparison of manufacturing processes used to produce API grade N-80 casing, (c) regression analysis of all available data to develop equations which can be used to predict cracking susceptibilty, and (d) study of a tempering heat treatment as a means of reducing the cracking susceptibility of molybdenum-bearing N-80 steels.

The present paper summarizes information on the influence of metallurgical variables on sulfide corrosion cracking. It provides a practical basis for the selection of commercial high-strength materials for tubular goods and wellhead fittings which are intended for use in sour gas and oil wells. No attempt has been made in this paper to review the various theories of sulfide corrosion cracking which are presently extant. The authors' own views regarding the mechanism of sulfide corrosion cracking have been presented elsewhere.[4,5]

Comparison of J-55, N-80, and P-110 Steels

Samples of API grades J-55, N-80, and P-110 steels from several different manufacturers have been tested for susceptibility to cracking using the procedure described by Fraser, Eldredge, and Treseder.[7] In brief, this procedure yields a number called the critical strain for cracking, S_c, which is characteristic of the alloy being tested. The critical strain for cracking, as used in this paper, is the strain ($x\ 10^3$) at which the probability of failure in the standard laboratory test is one-half. Very susceptible steels have low S_c values whereas non-susceptible steels have high S_c values. It should be noted that the critical strain is a function of the test conditions and environment as well as of the material tested and that the standard laboratory test environment is a severe one.

The average critical strain for cracking, S_c, of each of the different grades of steel tested is as follows:

Grade	No. Samples Tested	Average S_c	Standard Deviation
J-55	8	4.3	0.7
N-80	54	3.3	0.8
P-110	7	2.3	0.6

An analysis of variance shows that the

Abstract

A statistical study has been made of sulfide corrosion cracking of steel as a function of chemical composition, mechanical properties, and heat treatment. A total of 104 different alloys were studied, of which 79 were commercially-produced API grades J-55, N-80, and P-110 steels. It was possible to derive predictive equations which can be used to rate the cracking susceptibility of a new alloy from its known metallurgical properties. Resistance to cracking is increased most rapidly by increases in ductility and in carbon content. Resistance to cracking is decreased most rapidly by increases in hardness, strength, and manganese and molybdenum content. An additional result of this investigation is the demonstration that resistance to cracking can be markedly improved by tempering N-80 steel for one-half hour at 1100 F. The accompanying loss of yield strength is not excessive.   3.2.2

differences among the above classes are statistically quite significant.

Laboratory study of four samples of API grade N-80 steel tubular goods which had failed in service indicates that they were very susceptible to sulfide corrosion cracking. Details of the service conditions and metallurgy of these samples are shown in Table 2. However, note that fully half of the N-80 samples which were tested in the laboratory were more susceptible to cracking than one of the pieces of tubing which failed in service. This emphasizes the need for careful selection of oil well components as well as the desirability of having a heat treatment which can decrease the susceptibility of having a heat treatment which can decrease the susceptibility to cracking of API grade N-80 tubing.

Effect of Manufacturing Process

API grade N-80 steel pipe is made by four different manufacturing processes: normalizing, cold drawing, warm working, and quenching and tempering. It is reasonable to ask if the manufacturing process influences susceptibility to cracking. The average critical strain for cracking, S_c, of API grade N-80 steel produced by each of the different processes is shown in Table 3.

Variance analysis of these critical strains indicated that quenching and tempering produces pipe which has a significantly different critical strain from the other processes. However, multiple regression analysis (see Appendix A) indicated that the differences between N-80 produced by these four processes result largely from the differences in chemical composition and mechanical properties, not from the manufacturing processes themselves.

Effect of Composition and Mechanical Properties

A statistical analysis of the effect of composition and mechanical properties on resistance to cracking of API grades J-55, N-80, and P-110 steels is summarized in Appendix A. In general, within a given classification of steel, such as normalized N-80 steel, poor resistance to cracking is accompanied by high strength, low ductility, and high alloy content (especially manganese and mo-

lybdenum). This is shown both by the raw correlation coefficients of the individual variables with S_c (see Table 4) and by the predictive equations shown in Table 5, which have taken account of both the raw correlations and the cross-correlations between variables.

Predictive equations have been derived for each of several classes of steel, such as molybdenum-bearing N-80 steel, all low-alloy steels (including API grades J-55, N-80, and P-110), and all steels tested. For each class of steel, two equations are given in Table 5. These are: (1) the equation which gives the most accurate predicted value of the critical strain, S_c, and (2) a shorter equation which is easier to use but which still gives a reliable predicted value of the critical strain for cracking. The following examples of such shorter equations are the ones which appear to be handiest to use, and likely to be used most often:

A. For molybdenum-bearing N-80 steels:
$S_c = + 6.31$
$+ 6.18 \times$ (percent C)
$- 5.53 \times$ (percent Mo)
$+ 0.0611 \times$ (percent Reduction Area)
$- 0.1349 \times$ (Hardness, Rockwell A scale)

B. For low-alloy steels, including API grades J-55, N-80, and P-110 steels:
$S_c = + 2.92$
$- 1.061 \times$ (percent Mn)
$- 1.220 \times$ (percent Ni)
$- 0.00002359 \times$ (Yield Strength, psi)
$+ 0.1379 \times$ (percent Elongation)
$+ 0.837$ if normalized
or $+ 0.901$ if cold drawn or warm worked
or $+ 1.204$ if quenched and tempered

C. For any steel not included in the above classes:
$S_c = + 9.38$
$+ 3.65 \times$ (percent C)
$- 0.1346 \times$ (percent Ni)
$- 0.00001242 \times$ (Yield Strength, psi)
$- 0.1095 \times$ (Hardness, Rockwell A scale)

Examples of critical strain values computed for alloys within each of the above classifications follow:

A. Molybdenum-bearing N-80 steel:
Reference No. X-658
Measured $S_c = 1.7$
Properties: 0.42 percent C, 0.34 percent Mo, 53.0 percent Reduction Area, 63 R_A Hardness
Predicted $S_c = 1.8$

B. Quenched-and-tempered P-110 steel:
Reference No. X-439
Measured $S_c = 2.2$
Properties: 1.50 percent Mn, 0.09 percent Ni, 128,000 psi yield strength, 21.0 percent elongation; alloy was quenched and tempered
Predicted $S_c = 2.3$

C. 9 percent nickel steel:
Reference No. 7-171
Measured $S_c = 1.0$
Properties: 0.09 percent C, 8.77 percent Ni, 85,700 psi Yield Strength, 56 R_A Hardness
Predicted $S_c = 1.3$

The agreement between the measured and predicted values in each of the above examples happens to be good. It is not at all certain that equally-good agreement would be found in practice because the estimated error of prediction (see Table 5) is fairly large for most of the classes of steel studied. However, the predictive equations given above should be useful as a guide in choosing heats of steel which would most likely be safe for sour gas condensate service.

From previous laboratory and field experience data[4, 5, 6] it had been qualitatively deduced that high strength and hardness were to be avoided, as were high alloy content, especially of nickel and molybdenum. Conversely, high ductility appeared to be desirable. The present data confirm these observations in a quantitative fashion. However, there is one result from the statistical study which is contrary to early expectations: It had not been thought that resistance to cracking would have increased with carbon content. No satisfactory explanation can be offered for this phenomenon at this time. It may be noted that a similar beneficial influence of carbon in steel was noted by Parkins[9] in his studies of the stress corrosion cracking of mild steels in nitrate solutions. Parkins felt that the distribution of carbides (e.g., segregation at grain boundaries) was particularly important. No data are available at this time on the distribution of carbides in the steels which were studied.

With regard to the influence of mechanical properties on resistance to cracking, it has been suggested in an early paper by Prange[4] that there is a threshold hardness level above which steels are susceptible to cracking and below which they are not. Present data are consistent with the qualitative observations of Prange and others that high hardness levels are associated with increased susceptibility to cracking. However, these data do not indicate any nonlinearity in the relationship between hardness and S_c. It should be noted that sulfide corrosion cracking failures have been produced in specimens of quite soft steels (hardness values as low as 44 on the Rockwell A scale) when exposed in a highly strained condition to severe environments.

Effect of Tempering N-80

As pointed out above, half of the samples of API grade N-80 tubular goods tested in the laboratory have been more susceptible to sulfide corrosion cracking in the laboratory test than a piece of tubing which failed in the field. This suggests the need for some treatment to raise the S_c value of tubing and thus decrease the probability of failure by sulfide corrosion cracking. It is believed that the need for such a treatment remains even if the N-80 to be used is chosen by use of the equations in Table 5. This is because the estimated error of S_c values predicted by means of these equations is fairly large.

A practical treatment to raise the critical strain for cracking of API grade N-80 tubing is to temper the tubes after normalizing and straightening. As shown in Table 6, tempering for one-half hour at 1100 F markedly improved the resistance to cracking of ten different samples of molybdenum-bearing N-80 steel. In only one case did the S_c value appear to decrease. This steel already had a reasonably high initial S_c value, and the decrease was very small. The three steels which had lowest initial S_c

values all showed marked improvement on tempering. The same equation which predicts critical strain for as-received Mo-bearing N-80 steels adequately fits the data for tempered N-80.

The main disadvantage of tempering as a means of improving resistance to cracking is the accompanying decrease in yield strength. As shown in Table 2, tempering decreased the average yield strength of the ten N-80 steels to 81,000 psi, with four samples having yield strengths after tempering of less than 80,000 psi. The lowest observed yield strength was 74,900 psi. It is considered that the benefits which result from an increase in resistance to cracking would more than offset the disadvantages of a decrease in yield strength. It appears preferable to accept the decreased minimum yield strength and design tubing strings on this basis rather than to insist on a minimum yield strength after tempering of 80,000 psi. This is because increased resistance to cracking which results from tempering appears to be largely associated with the decrease in yield and ultimate strength, rather than with any microstructural changes.

Acknowledgment

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APPENDIX A—Statistical Analysis of the Prediction of Critical Strain

The critical strain for sulfide corrosion cracking may be compared with the various mechanical, chemical, and heat treatment factors to determine relationships. In general, the factors that give high strength give poor or low critical strain. The correspondence between critical strain, S_c, and any factor, X, can be represented by a correlation coefficient.

$$r = \Sigma sx / \sqrt{\Sigma s^2 \Sigma x^2} \qquad (1)$$

where $s = S_c -$ average S_c and $x = X$ $-$ average X. (These lower case letters with these meanings will be used in this appendix to simplify explanations.)

A perfect linear correspondence between the critical strain and the factor gives a correlation coefficient of plus or minus unity; no linear correspondence gives a coefficient of zero. To be significant it is necessary that correlation coefficients be substantially different from zero, the amount depending on the number of tests concerned. For example, for 95 percent confidence limit, and $N = 37$ alloys, r should be greater than

TABLE 1—Metallurgical Properties of Alloys Tested

Alloy Ref. No.	Code[a]	C	Mn	P	S	Si	Mo	Ni	Cr	Cu	Al	By[b]	Y.S., psi	U.T.S., psi	El., %	R.A., %	H[c]	No. Tests	S.
J-55 Steels:																			
7100	JN04	0.25	0.57	0.001	0.018	0.24	0.01	0.02	0.00	0.05	0.00	D	45300	91600	26.7	43.0	50	5	5.7
7109	JN07	0.40	0.72	0.003	0.020	0.14	0.00	0.03	0.01	0.04	0.00	D	54200	92300	29.7	53.3	53	9	5.1
7124	JN59	0.51	1.10	0.024	0.022	0.21	0.00	0.03	0.03	0.02	0.00	D	57700	108700	25.7	49.0	55	24	4.1
7140	JN40	0.48	1.21	0.017	0.015	0.18	0.01	0.02	0.02	0.00	0.01	D	59700	115200	25.7	51.0	58	24	3.7
7141	JN40	0.44	1.12	0.013	0.011	0.18	0.01	0.03	0.02	0.00	0.00	D	57700	108200	26.7	55.0	57	24	3.8
7142	JN40	0.30	1.00	0.061	0.019	0.19	0.00	0.00	0.00	0.00	0.00	D	61800	105800	27.0	50.0	56	32	4.1
7143	JN40	0.34	0.91	0.050	0.010	0.24	0.01	0.02	0.03	0.00	0.01	D	61700	101200	28.0	45.7	55	24	3.6
7150	JE68	0.28	1.41	0.014	0.034	0.20	0.00	0.04	0.03	0.05	0.01	D	58700	72800	31.3	69.3	49	24	3.8
Mo-Bearing N-80 Steels:																			
7095	NN58	0.40	1.70	0.037	0.029	0.16	0.17	0.13	0.15	0.06	0.02	D	87000*	112800	25.0	61.0	61	16	3.6
7099	NN04	0.35	1.35	0.002	0.020	0.22	0.15	0.03	0.01	0.05	0.02	D	87000	122000	25.0	57.0	57	12	3.9
7108	NN41	0.38	1.31	0.007	0.020	0.25	0.31	0.13	0.09	0.11	0.03	D	88700	120000	22.0	56.3	61	42	2.8
7144	NN66	0.45	1.66	0.019	0.008	0.12	0.20	0.02	0.03	0.00	0.03	D	72000	129700	23.0	54.3	62	24	2.5
7145	NN66	0.40	1.55	0.023	0.010	0.04	0.21	0.05	0.02	0.01	0.01	D	73000	119500	23.7	54.8	61	24	3.1
7154	NN58	0.35	1.66	0.014	0.034	0.20	0.21	0.02	0.02	0.19	0.02	M	68300	104500	25.3	60.3	56	9	3.7
7155	NN57	0.42	1.85	0.020	0.030	0.17	0.25	0.10	0.13	0.08	0.02	M	97000	131000	19.7	51.7	63	9	2.3
X059C	NN42	0.42	1.75	0.019	0.030	0.25	0.18	0.03	0.03	0.10	0.02	D	103700	130100	21.0	50.7	62	16	2.2
X188A	NN04	0.40	1.37	0.019	0.018	0.21	0.25	0.03	0.10	0.08	0.01	D	90000	119000	24.0	59.0	61	5	2.9
X188B	NN04	0.40	1.33	0.023	0.020	0.18	0.25	0.03	0.10	0.08	0.04	D	89100	121700	22.3	60.3	61	5	2.7
X218	NN04	0.49	1.45	0.019	0.031	0.26	0.19	0.03	0.04	0.02	0.02	D	84300	125000	22.8	55.8	62	50	3.3
X243	NN04	0.40	1.52	0.030	0.032	0.13	0.26	0.12	0.05	0.18	0.03	D	94000	119800	19.0	56.5	62	40	2.0
X355A	NN05	0.43	1.38	0.019	0.025	0.20	0.15	0.07	0.06	0.10	0.02	M	78800	123200	23.3	59.0	59	14	4.8
X355B	NN05	0.43	1.36	0.023	0.023	0.20	0.16	0.07	0.05	0.06	0.03	M	77300	115800	24.5	61.2	57	15	4.0
X355C	NN05	0.45	1.38	0.018	0.026	0.20	0.15	0.07	0.04	0.05	0.04	M	83000	118600	25.2	60.0	59	15	4.1
X355D	NN05	0.43	1.36	0.017	0.022	0.19	0.16	0.04	0.03	0.05	0.03	M	80000	118200	24.5	61.7	59	12	4.7
X355E	NN05	0.45	1.38	0.018	0.022	0.19	0.16	0.07	0.06	0.09	0.00	M	75300	120500	25.2	59.7	59	14	3.8
X355F	NN05	0.44	1.38	0.019	0.026	0.20	0.15	0.06	0.05	0.10	0.02	M	76000	117300	26.8	62.3	60	17	3.9
X3568	NN05	0.41	1.33	0.017	0.025	0.22	0.18	0.09	0.05	0.14	0.03	M	76700	113900	23.0	52.3	59	16	3.3
X361	NN04	0.45	1.60	0.030	0.025	0.26	0.30	0.10	0.04	0.08	0.07	D	102000	129200	20.0	55.7	62	32	2.4
X376A	NN04	0.40	1.33	0.017	0.024	0.21	0.22	0.08	0.04	0.19	0.03	M	87000	117500	23.3	58.7	60	14	3.2
X376B	NN04	0.41	1.34	0.017	0.024	0.22	0.23	0.09	0.04	0.22	0.05	M	86800	118800	22.7	56.7	60	17	3.2
X378A	NN04	0.40	1.40	0.017	0.036	0.19	0.15	0.07	0.04	0.04	0.02	M	75500	105300	27.2	63.3	56	16	3.8
X378B	NN04	0.45	1.48	0.019	0.028	0.19	0.17	0.06	0.04	0.03	0.03	M	86000	120200	22.6	56.3	60	16	3.4
X378C	NN04	0.45	1.50	0.023	0.031	0.25	0.16	0.07	0.04	0.03	0.03	M	82300	123900	21.0	50.6	61	14	3.3
X378D	NN04	0.38	1.46	0.026	0.031	0.17	0.15	0.07	0.04	0.03	0.07	M	78300	106800	27.5	63.6	57	13	3.7
X384A	NN04	0.37	1.40	0.016	0.022	0.21	0.16	0.07	0.04	0.04	0.02	M	78800	109100	26.6	62.0	57	14	3.4
X384B	NN04	0.40	1.44	0.014	0.028	0.22	0.16	0.06	0.04	0.03	0.03	M	82000	112700	24.3	60.3	58	13	4.1
X416A	NN05	0.37	1.75	0.020	0.042	0.21	0.24	0.05	0.06	0.05	0.03	M	84700	118000	20.7	61.8	60	18	2.6
X416B	NN05	0.36	1.50	0.016	0.028	0.14	0.25	0.06	0.07	0.06	0.03	M	87300	118100	21.8	62.0	60	15	2.1
X416C	NN05	0.38	1.76	0.017	0.027	0.21	0.24	0.12	0.06	0.04	0.04	M	92700	118200	21.0	62.0	59	16	2.7
X416D	NN05	0.34	1.46	0.017	0.030	0.14	0.22	0.05	0.06	0.04	0.02	M	80700	109300	24.0	63.5	58	16	3.6
X416E	NN05	0.37	1.56	0.016	0.031	0.15	0.23	0.05	0.05	0.03	0.03	M	88300	114900	22.5	63.0	59	14	3.1
X416F	NN05	0.39	1.69	0.016	0.027	0.18	0.24	0.06	0.07	0.03	0.03	M	84100	115300	23.0	63.0	60	14	3.3
X513	NN43	0.43	1.83	0.023	0.025	0.26	0.27	0.04	0.04	0.13	0.03	D	88000*	126700	18.7	51.0	59	13	2.3
X631	NN05	0.40	1.83	0.025	0.025	0.18	0.32	0.06	0.04	0.06	0.03	D	100500	127500	21.0	59.0	63	10	1.9
X658	NN64	0.40	1.90	0.020	0.025	0.17	0.34	0.17	0.12	0.07	0.00	D	100500	131000	19.0	53.0	63	10	1.7
Mo-Bearing N-80 Steels, before and after tempering:																			
X059C	NN42	0.42	1.75	0.019	0.030	0.25	0.18	0.03	0.03	0.10	0.02	D	103700	130100	21.0	50.7	62	16	2.2
T059C													86000*	113600	23.3	57.0	58	12	3.2
X218	NN04	0.49	1.45	0.019	0.041	0.26	0.19	0.03	0.04	0.02	0.02	D	84300	125000	22.8	55.8	62	50	3.3
T218													84500*	111400	26.6	61.6	59	12	3.9
X243	NN04	0.40	1.52	0.030	0.032	0.13	0.26	0.12	0.05	0.18	0.03	D	94000	119800	19.0	56.5	62	40	2.0
T243													79800*	103000	28.0	66.0	57	6	3.8
X355A	NN05	0.43	1.38	0.019	0.025	0.20	0.15	0.07	0.06	0.10	0.02	M	78800	123200	23.3	59.0	59	14	4.8
T355A													78100*	109100	27.2	64.7	57	5	5.7
X355F	NN05	0.44	1.38	0.019	0.026	0.20	0.15	0.06	0.05	0.10	0.02	M	76000	117300	26.8	62.3	60	17	3.9
T355F													82700*	113000	25.7	60.7	59	10	5.2
X361	NN04	0.45	1.60	0.030	0.025	0.26	0.30	0.10	0.04	0.08	0.07	D	102000	129200	20.0	55.7	62	32	2.4
T361													83300*	110800	25.2	62.3	55	12	4.1
X378B	NN04	0.45	1.48	0.019	0.028	0.19	0.17	0.06	0.04	0.03	0.03	M	86000	120200	22.6	56.3	60	16	3.4
T378B													83300*	110500	25.0	58.0	58	12	3.4
X384A	NN04	0.37	1.40	0.016	0.022	0.21	0.16	0.07	0.04	0.04	0.02	M	78800	109100	26.6	62.0	57	14	3.4
T384A													74900*	101800	28.0	62.3	56	12	3.5
X416B	NN05	0.36	1.50	0.016	0.028	0.14	0.25	0.06	0.07	0.06	0.03	M	87300	118100	21.8	62.0	60	15	2.1
T416B													80700*	106400	25.2	61.0	58	11	3.6
X446D	NN05	0.34	1.46	0.017	0.030	0.14	0.22	0.05	0.06	0.04	0.02	M	80700	109300	24.0	63.5	58	16	3.6
T416D													78300*	102300	27.5	64.7	56	12	3.4
Cold Drawn and Warm Worked N-80 Steels:																			
7146	NW56	0.39	1.23	0.009	0.025	0.16	0.01	0.05	0.02	0.02	0.00	D	86500	116700	20.0	48.7	59	32	3.3
7147	NW56	0.39	1.17	0.010	0.015	0.17	0.01	0.03	0.02	0.00	0.02	D	85500	115700	19.7	48.7	57	24	2.9
X188C	NC57	0.46	0.85	0.021	0.019	0.08	0.00	0.07	0.06	0.13	0.03	D	86900	115900	18.7	43.0	60	12	3.2
X188D	NC58	0.48	1.00	0.025	0.017	0.09	0.03	0.03	0.03	0.12	0.02	D	96300	127100	18.0	44.3	62	12	3.2
X351A	NW42	0.42	1.02	0.020	0.025	0.15	0.02	0.07	0.03	0.06	0.02	M	87700	111900	19.7	49.0	58	9	3.0

TABLE 1—Metallurgical Properties of Alloys Tested—(Continued)

Alloy Ref. No.	Code[a]	C	Mn	P	S	Si	Mo	Ni	Cr	Cu	Al	By[b]	Y.S., psi	U.T.S., psi	El., %	R.A., %	H[e]	No. Tests	S_c
**Cold Drawn and Warm Worked N-80 Steels (Continued):**
X351B	NW41	0.41	1.22	0.025	0.026	0.17	0.02	0.07	0.03	0.06	0.02	M	98700	123500	17.3	51.0	60	13	3.1
X3561	NC42	0.40	0.89	0.012	0.020	0.14	0.00	0.07	0.06	0.11	0.01	M	79000	103500	20.5	56.0	57	14	3.1
X3562	NC42	0.42	0.91	0.015	0.020	0.13	0.00	0.07	0.06	0.10	0.01	M	89700	114600	19.0	49.6	56	14	3.0
X3563	NC42	0.41	0.92	0.014	0.020	0.14	0.00	0.07	0.07	0.11	0.01	M	84000	112900	19.2	54.6	57	14	3.1
X3564	NC41	0.41	0.22	0.017	0.040	0.20	0.00	0.05	0.04	0.10	0.01	M	85000	113400	19.7	53.0	59	14	3.1
X3565	NC41	0.43	0.94	0.022	0.038	0.21	0.00	0.05	0.04	0.10	0.02	M	87000	113600	17.8	50.3	56	13	3.2
X3566	NC41	0.43	0.95	0.020	0.040	0.20	0.01	0.08	0.04	0.15	0.00	M	90200	116800	19.2	51.4	59	10	3.3
X3567	NC41	0.45	0.96	0.018	0.038	0.14	0.01	0.08	0.03	0.12	0.00	M	97700	123200	16.8	47.0	58	9	4.2
**Quenched and Tempered N-80 and P-110 Steels:**
7122	PQ57	0.35	1.50	0.021	0.022	0.18	0.00	0.05	0.02	0.02	0.01	D	124800	137500	22.3	62.5	64	24	3.2
X334A	NQ55	0.35	0.76	0.020	0.033	0.11	0.00	0.07	0.04	0.02	0.01	D	98800	114400	21.3	62.0	61	16	4.0
X334B	NQ55	0.40	0.86	0.020	0.050	0.06	0.00	0.06	0.04	0.04	0.01	D	99000	119500	21.0	60.0	61	15	4.0
X334C	NQ41	0.33	0.78	0.008	0.040	0.05	0.00	0.05	0.03	0.11	0.00	M	86800	110000	24.3	66.0	58	10	4.6
X351C	PQ56	0.34	1.35	0.019	0.028	0.14	0.02	0.07	0.02	0.04	0.00	M	138300	148500	19.2	60.0	65	10	1.4
X351D	PQ56	0.28	1.26	0.020	0.026	0.15	0.01	0.05	0.02	0.04	0.00	M	115000	130800	19.8	62.0	61	11	2.4
X415A	PQ78	0.30	1.33	0.021	0.030	0.20	0.01	0.09	0.07	0.08	0.03	M	119500	131700	20.3	63.0	63	13	2.7
X415B	PQ78	0.33	1.54	0.016	0.037	0.23	0.00	0.09	0.07	0.08	0.03	M	119500	130700	20.3	63.0	62	13	2.3
X415C	PQ78	0.31	1.49	0.017	0.028	0.22	0.00	0.10	0.08	0.08	0.03	M	133500	143300	20.2	63.0	64	17	1.7
X417A	NQ04	0.24	0.91	0.015	0.031	0.16	0.00	0.05	0.04	0.02	0.02	M	83800	100600	27.3	76.7	57	6	5.7
X417B	PQ05	0.28	1.58	0.016	0.028	0.17	0.00	0.03	0.03	0.02	0.00	M	125500	137500	20.3	63.3	64	15	2.0
**Magnet Iron:**
7152	I	0.04	0.03	0.013	0.025	0.00	0.00	0.06	0.02	0.10	0.10	D	48200	58800	27.0	69.5	44	24	2.1
**Chromium Steels:**
7101	X04	0.08	0.40	0.016	0.006	0.24	0.50	0.50	4.85	0.00	....	D	97300	139600	26.0	64.3	66	24	0.8
7102	X04	0.09	0.41	0.018	0.008	0.70	0.50	0.50	6.65	0.00	....	D	126300	157500	23.7	61.3	66	12	0.9
7103	X04	0.09	0.35	0.009	0.011	0.33	0.91	0.24	8.41	0.12	0.08	D	158200	185000	20.0	57.7	70	20	0.6
7156	X04	0.12	0.51	0.012	0.010	0.63	0.99	0.30	8.65	0.13	....	M	90070	129100	23.0	68.3	64	11	1.7
8085	X04	0.05	0.45	0.009	0.011	0.55	0.30	0.30	12.40	0.72	0.02	D	101700	141900	24.0	62.7	65	16	1.3
8087	V	0.08	0.49	0.023	0.020	0.80	0.30	0.50	12.10	0.00	....	D	55000	83900	29.0	59.3	50	12	3.4
X0864	V	0.15	0.56	0.030	0.040	0.66	0.11	0.18	12.50	0.00	0.00	D	118300*	134300	17.0	54.7	64	18	1.2
X410	V	0.19	0.77	0.015	0.028	0.49	0.97	0.79	13.31	0.00	....	M	128800	157200	10.0	16.0	66	7	1.2
**Nickel Steels:**
7096	X04	0.09	0.43	0.002	0.014	0.27	0.30	4.83	0.05	0.00	....	D	60900	99100	36.3	69.0	59	27	0.7
7117	X04	0.12	0.46	0.016	0.013	0.23	0.06	4.90	0.21	0.11	0.02	D	65900	98800	36.3	70.3	54	24	1.1
X314B	X04	0.11	0.50	0.020	0.020	0.20	0.04	8.78	0.12	0.27	....	D	146000	172000	13.0	55.0	69	11	0.2
X205	X05	0.13	0.61	0.029	0.038	0.18	0.04	8.50	0.15	0.50	0.02	D	134500	143300	21.3	63.0	65	24	0.5
7106	X05	0.08	0.39	0.018	0.023	0.19	0.09	8.82	0.20	0.28	0.04	D	106000	125600	26.0	66.0	63	31	0.7
7097	X04	0.10	0.45	0.025	0.014	0.20	0.30	8.91	0.05	0.32	....	D	99500	117000	26.6	71.2	61	12	0.9
7171	X04	0.09	0.53	0.016	0.021	0.25	0.07	8.77	0.04	0.30	0.00	M	85700	101500	27.3	68.7	56	12	1.1
**High Strength, Low Alloy Structural Steel:**
X382	XQ	0.17	0.90	0.015	0.028	0.27	0.48	0.74	0.88	0.33	0.07	M	114500	121100	20.5	64.0	61	12	2.1
**SAE 4140 Steel:**
X212A	V	0.40	0.85	0.004	0.004	0.30	0.20	0.40	1.00	0.00	....	N	130100	148400	22.3	60.0	65	19	1.6
**Other Steels Used in Oil Field Tubular Goods:**
7098	X 05	0.33	0.71	0.010	0.010	0.25	0.30	1.64	0.75	0.06	0.02	D	125600	148000	20.0	56.3	64	24	0.7
X507A	NN04	0.30	0.45	0.020	0.020	0.24	0.36	2.35	1.08	0.07	0.01	D	85300	112200	25.7	67.0	59	13	2.2
X507B	PN04	0.30	0.45	0.020	0.020	0.23	0.31	1.95	0.98	0.06	0.03	D	114700	139500	21.3	61.0	64	13	1.0
X450A	PN05	0.28	2.60	0.016	0.032	0.23	0.19	0.03	0.03	0.08	0.06	M	130500	150500	20.7	58.0	66	10	1.1
X450B	PN43	0.49	1.75	0.022	0.017	0.22	0.20	0.20	0.60	0.19	0.01	M	109200	138800	21.0	61.0	62	11	2.7
X703	P 04	0.40	1.45	0.015	0.016	0.25	0.23	0.53	0.58	0.00	0.00	M	128000	153000	17.7	58.7	64	11	0.9
7125	L	0.20	0.40	0.020	0.020	0.02	0.00	0.04	0.04	0.04	0.00	D	53100	74900	27.3	46.0	48	8	5.2
**Steels Tested but not Included in Statistical Study:**
85907	V	0.12	0.45	0.019	0.012	0.46	....	0.18	12.30	....	....	D	....	....	....	....	70	12	0.9
85910	V	0.12	0.45	0.019	0.012	0.46	....	0.18	12.30	....	....	D	....	....	....	....	66	11	1.5
85211	V	0.12	0.45	0.019	0.012	0.46	....	0.18	12.30	....	....	D	....	....	....	....	61	12	1.9
7168	X	0.12	0.36	0.015	0.014	0.99	0.50	....	3.02	....	0.52	M	90000	115000	23.0	64.0	50	8	2.7
7169	X	0.13	0.34	0.014	0.010	0.87	0.54	....	5.00	....	0.52	M	105000	121000	20.0	63.0	59	8	1.6
X439	PQ57	0.32	1.50	0.017	0.070	0.14	0.01	0.09	0.09	0.08	0.03	M	128000	140000	21.0	63.0	66	12	2.2
7153	X 04	....	....	....	....	....	0.00	8.00	0.35	0.30	0.02	S	....	....	....	....	59	16	0.9

[a] Code designation for size, grade, etc: **First Column (Grade):** J = API Grade J-55, N = API Grade N-80, P = API Grade P-110, X = Non-API material (usually alloy steel), V = Valve alloy, I = Ingot iron; **Second Column (Method of Manufacture):** C = Cold drawn, N = Normalized, Q = Quenched and tempered, W = Warm worked, E = Electric welded; **Third and Fourth Columns (Weight and grade of pipe):** 04 = 2⅜″ tubing, 05 = 2⅞″ tubing, 07 = 3½″ 9.20 lb tubing, 39 = 5½″ 14 lb casing, 40 = 5½″ 15.5 lb casing, 41 = 5½″ 17 lb casing, 42 = 5½″ 20 lb casing, 43 = 5½″ 23 lb casing, 45 = 6″ 18 lb casing, 46 = 6″ 20 lb casing, 55 = 7″ 23 lb casing, 56 = 7″ 26 lb casing, 57 = 7″ 29 lb casing, 58 = 7″ 32 lb casing, 59 = 7″ 35 lb casing, 64 = 7⅝″ 29.7 lb casing, 66 = 7⅝″ 39 lb casing, 68 = 8⅝″ 28 lb casing, 78 = 9⅝″ 43.5 lb casing.

[b] M = reported by manufacturer. However, in cases where Ni, Cr, Cu, and Al were not deliberate alloying additions, these were not reported by the manufacturer. The values shown were from spectroscopic analyses and are believed correct within ± 15 percent of value shown or 0.01 percent, whichever is larger. D = determined in these laboratories. Values for C, Mn, P, and S determined by chemical analysis, whereas other alloying additions were from spectroscopic analyses. S = spectroscopic analysis.

[c] Determined on Hounsfield tensometer, using 1/40 sq inch x 0.632-inch long tensile bars. Results shown are average for three tensile bars. Yield strength shown is the stress at 0.5 percent strain (see API Standard 5A) except where a distinct yield point was observed. If a distinct yield was observed, this is indicated by an asterisk.

[d] Values of S_c determined by standard laboratory as described in Reference 7. The maximum nominal applied strain used in this study was 0.00533 inch/inch A few alloys showed no failure at this strain; the S_c value shown for these alloys is 5.7 (Alloy Reference Numbers 7100, T 355 A, and X 417 A).

[e] Hardness values on the Rockwell A scale. Values shown are average of five measurements.

TABLE 2—Summary of Information on Failed Tubular Goods Examined in the Laboratory

PROPERTY	Sour Gas Well 9,973 Ft. Depth Gas Composition: 3.5% H₂S, 6.0% CO₂	Sour Gas Well 12,126 Ft. Depth Gas Composition: 42% H₂S, 5% CO₂		Sour Oil Well 11,884 Ft. Depth Gas Composition: 20% H₂S, 5% CO₂
Production Rate:				
Gas, mmcf/d	5.6	4.0		Not available*
Oil, bbl/d	56	203		200 originally; declined to 3 before failure.
Water, bbl/d	26	......		Not available*
Bottom Hole Pressure, psi	3,835	6,000		5,210
Bottom Hole Temperature, Degrees F	198	250		229
Shut-In Tubing Pressure, psi	2,867	3,400		Not available*
Flowing Tubing Pressure, psi	2,674	3,096		200–300
Flowing Wellhead Temperature, Degrees F	104	Not available*		Not available*
Depth of Failure, ft	1,429	1,264	1,141	292
Failure Occured In	2⅞″ N-80 tubing	5½″ N-80 casing	5½″ N-80 casing	2⅞″ N-80 tubing
Brief Description	Well flowed 26 mmcf total on test then shut in.	Failed at thread after 69 hr total production. Casing dropped 8-10 ft.	Spiral crack in body, ca 16″ long.	Well worked over ca 1 month before failure.
Estimated Applied Stress at Point of Failure, psi	25,100	45,000	Not reported	36,800
Laboratory Reference No. of Steel	X-218	X-059C	X-513	X-631
Composition of Steel:				
C	0.49	0.42	0.43	0.40
Mn	1.45	1.75	1.83	1.83
P	0.019	0.019	0.025	0.025
S	0.041	0.030	0.023	0.025
Si	0.26	0.25	0.26	0.18
Mo	0.20	0.18	0.27	0.32
Ni	0.03	0.03	0.04	0.06
Cr	0.04	0.03	0.04	0.04
Cu	0.02	0.10	0.13	0.06
Al	0.031	0.03	0.026	0.034
Mechanical Properties:				
Yield Strength, psi	No yield	No yield	No yield	No yield
Offset Yield, psi	84,300	103,700	97,500	100,500
Ultimate Tensile Strength, psi	125,000	130,100	126,700	127,500
Elongation, %	22.8	21.0	18.7	21.0
Reduction Area, %	55.8	50.7	51.0	59.0
Hardness, Rₑ	23	23	20	25
Sₑ in Laboratroy Test	3.3	2.2	2.3	1.9
Rₑ from Field Tests	ca4.4	**	**	**

* Not reported with other data regarding this failure.
** Not determined.

TABLE 4—Correlation of Critical Strain for Cracking with Metallurgical Variables

	CORRELATION COEFFICIENTS					
Required for Significance[b]	37 Mo-Bearing N-80 Steels	47 Mo-Bearing N-80 Steels[a]	68 Non-Heat Treated J-55 and N-80 Steels	79 API Grade J-55 N-80, and P-110 Steels	86 Low Alloy Steels	104 Alloys
	.325	.288	.239	.222	.212	.193
Property:						
C	+.145	+.217	−.049	+.027	+.136	+.552
Mn	−.614	−.571	−.437	−.476	−.236	+.250
P	−.164	−.022	−.123	−.084	+.266	−.303
S	+.036	+.055	−.061	−.002	+.189	+.266
Si	+.065	+.082	+.111	−.008	−.179	−.329
Mo	−.789	−.655	−.391	−.240	−.407	−.268
Cr	−.234	−.208	−.273	−.283	−.531	−.339
Ni	−.244	−.159	−.336	−.272	−.432	−.509
Cu	−.188	−.072	−.070	−.079	+.094	+.076
Yield Strength	−.703	−.638	−.642	−.629	−.669	−.652
Ultimate Tensile Strength	−.573	−.559	−.551	−.649	−.684	−.609
Elongation	+.754	+.727	+.603	+.624	+.587	+.314
Reduction Area	+.465	+.522	+.110	−.125	+.272	−.092
Hardness	.655	−.617		−.612	−.639	−.664	−.618
N[c]	......	......	......	−.061	−.145	+.305
W[c]	......	......	......	−.084	−.002	+.089
Q[c]	......	......	......	+.124	−.076	−.152

[a] Includes ten samples tested in both the as-received condition and after tempering ½ hr at 1100 F.
[b] Magnitude of correlation coefficient required for significance at 95 percent significance level.
[c] There are four commercially used metallurgical treatments used in producing casing and tubing. These are as follows:

N—normalized after rolling.
W—worked either by cold drawing or by "warm working" at about 1000 to 1100 F.
Q—quenched and tempered.
J—no special heat treatment after rolling at a high temperature.

Each alloy tested will fit into one of the above categories. However, use of all four categories in a regression analysis is redundant. Therefore, variable J has been omitted.

TABLE 3—Critical Strain for Cracking of API Grade N-80 Steel Manufactured by Different Processes

Manufacturing Process	No of Samples Tested	Average Sₑ	Standard Deviation
Normalizing	37	3.2	0.8
Cold Drawing	9	3.3	0.4
Warm Working	4	3.1	0.2
Quenching and Tempering	4	4.6	0.8

0.325; and for N = 104, r should be greater than 0.193. The correlations of critical strain, Sₑ, with various composition and mechanical property variables are given in Table 4.

This correspondence between Sₑ and any one factor X also can be represented by a prediction or regression equation.

$$\text{Predicted } S_e = A + bX, \text{ or} \quad (2)$$

$$\text{Predicted } s = bx \quad (3)$$

The value of b for the best linear prediction, according to the method of least squares is

$$b = \Sigma sx / \Sigma x^2 \quad (4)$$

so

$$\text{Predicted } s = \Sigma sx \frac{1}{\Sigma x^2} X \quad (5)$$

and the standard error of estimate or prediction is

$$\sqrt{(\Sigma s^2)(1 - r^2)/(N - 2)} \text{ or}$$

$$\sqrt{\left[\Sigma s^2 - \frac{(\Sigma sx)^2}{(\Sigma x^2)}\right]/(N - 2)}$$

A predictive or regression equation can also be written between Sₑ and more than one factor $X_1, X_2, X_3 \ldots$

$$\text{Predicted } s = b_1 x_1 + b_2 x_2 + b_3 x_3 \ldots \quad (6)$$

It must be rembered here that the various factors may be correlated with each other, and use of all would be redundant. For example, ultimate strength is strongly correlated with yield strength. Note that ultimate strength, U.S., which shows correlations in Table 4, does not appear in the equations in Table 5.

Conversely, a variable with little or no apparent correlation with critical strain may be an important variable after the effects of other variables have been accounted for. Note the low or even negative correlations of carbon in Table 4 although carbon increases critical strain in the equations of Table 5. Thus, the best value of each b to predict critical strain will depend on all the correlations with Sₑ and the cross correlations of the independent factors. These b's have been obtained; the predictive equations are given in Table 5.

The method of obtaining the best equations is known as multiple regression analysis[6]. For more than three independent variables, a hand calculated regression analysis becomes very complicated. The authors were fortunate to have a high-speed digital computer with an already-prepared program to use in finishing this work.

In the analysis of sulfide corrosion cracking data, a total of 17 different metallurgical variables were measured on each steel sample in addition to the

TABLE 5—Equations for Predicting Critical Strain for Cracking, S_c, from Metallurgical Data

EQUATION	Significance of Variable, t	Standard Error of Estimate, S.E.
A. 37 Mo-Bearing N-80 Steels:		
1. Four Variables:		
$S_c = +6.48$		±1.17
$+7.37 \times \% \text{ C}$	2.75	
$-6.21 \times \% \text{ Mo}$	3.36	
$+0.0589 \times \% \text{ Reduction Area}$	2.88	
$-0.1415 \times \text{Hardness, } R_A$	2.48	
2. Best Predictive Equation Found:		
$S_c = +8.94$		±1.08
$+6.85 \times \% \text{ C}$	2.71	
$-0.792 \times \% \text{ Mn}$	1.95	
$-4.66 \times \% \text{ Mo}$	2.57	
$+3.65 \times \% \text{ Cr}$	1.58	
$-0.00001570 \times \text{Yield Strength, psi}$	1.54	
$+0.0435 \times \% \text{ Reduction Area}$	2.21	
$-0.1304 \times \text{Hardness, } R_A$	2.16	
Limit for 95% confidence for any one term	t > 2.04	
Limit for 99% confidence for any one term	t > 2.75	
B. 47 Mo-Bearing N-80 Steels (Including 10 which were Tempered):		
1. Four Variables:		
$S_c = +6.32$		±1.15
$+6.18 \times \% \text{ C}$	3.11	
$-5.54 \times \% \text{ Mo}$	3.85	
$+0.0611 \times \% \text{ Reduction Area}$	3.51	
$-0.1350 \times \text{Hardness, } R_A$	3.04	
2. Best Predictive Equation Found:		
$S_c = +8.59$		±0.99
$+6.23 \times \% \text{ C}$	3.53	
$-0.752 \times \% \text{ Mn}$	2.36	
$+11.99 \times \% \text{ P}$	1.16	
$-3.71 \times \% \text{ Mo}$	3.26	
$+4.25 \times \% \text{ Cr}$	2.37	
$-0.00001802 \times \text{Yield Strength, psi}$	2.40	
$+0.0470 \times \% \text{ Reduction Area}$	2.78	
$-0.1231 \times \text{Hardness, } R_A$	2.48	
Limit for 95% confidence for any one term	t > 2.02	
Limit for 99% confidence for any one term	t > 2.70	
C. 68 Non-heat Treated J-55 and N-80 Steels, but Including 10 Tempered Mo-bearing N-80 Steels:		
1. Four Variables:		
$S_c = +6.15$		±1.13
$+6.87 \times \% \text{ C}$	3.99	
$-5.84 \times \% \text{ Mo}$	4.60	
$+0.06177 \times \% \text{ Reduction Area}$	4.14	
$-0.1362 \times \text{Hardness, } R_A$	3.41	
2. Best Predictive Equation Found:		
$S_c = +8.15$		±1.00
$+6.73 \times \% \text{ C}$	4.27	
$-0.726 \times \% \text{ Mn}$	2.48	
$+10.02 \times \% \text{ P}$	1.19	
$-5.08 \times \% \text{ Mo}$	4.00	
$+3.65 \times \% \text{ Cr}$	2.26	
$-0.00001632 \times \text{Yield Strength, psi}$	2.42	
$+0.0469 \times \% \text{ Reduction Area}$	3.17	
$-0.1210 \times \text{Hardness, } R_A$	2.82	
Limit for 95% confidence for any one term	t > 2.00	
Limit for 99% confidence for any one term	t > 2.66	
D. 79 API Grade J-55, N-80, and P-110 Steels:		
1. Five Variables:		
$S_c = +8.21$		±1.52
$+4.45 \times \% \text{ C}$	3.34	
$-1.697 \times \% \text{ Mn}$	2.01	
$+0.1068 \times \% \text{ Elongation}$	2.05	
$-0.1246 \times \text{Hardness, } R_A$	1.52	
$+0.726$ if normalized (N)	3.17	
or $+0.927$ if quenched and tempered (Q)	2.95	

EQUATION	Significance of Variable, t	Standard Error of Estimate, S.E.
2. Best Predictive Equation Found:		
$S_c = +7.63$		±1.47
$+3.42 \times \% \text{ C}$	2.35	
$-1.220 \times \% \text{ Mn}$	3.34	
$-2.50 \times \% \text{ Mo}$	1.52	
$-0.00001940 \times \text{Yield Strength, psi}$	2.01	
$+0.0857 \times \% \text{ Elongation}$	2.20	
$-0.0858 \times \text{Hardness, } R_A$	2.05	
$+1.358$ if normalized (N)	3.71	
or $+0.469$ if cold drawn (C) or warm worked (W)	1.22	
or $+1.514$ if quenched and tempered (Q)	3.10	
Limit for 95% confidence for any one term	t > 1.99	
Limit for 99% confidence for any one term	t > 2.64	
E. 86 Low-alloy Steels:		
1. Five Variables:		
$S_c = +2.923$		±1.56
$-1.062 \times \% \text{ Mn}$	3.26	
$-1.222 \times \% \text{ Ni}$	4.54	
$-0.00002695 \times \text{Yield Strength, psi}$	3.05	
$+0.1381 \times \% \text{ Elongation}$	4.11	
$+0.838$ if normalized (N)	3.33	
or $+0.868$ if cold drawn (C) or warm worked (W)	2.69	
or $+1.205$ if quenched and tempered (Q)	3.13	
2. Best Predictive Equation Found:		
$S_c = +2.844$		±1.50
$+1.807 \times \% \text{ C}$	1.29	
$-0.900 \times \% \text{ Mn}$	2.74	
$+12.34 \times \% \text{ P}$	1.04	
$+17.52 \times \% \text{ S}$	1.90	
$-0.897 \times \% \text{ Ni}$	3.15	
$-0.00003061 \times \text{Yield Strength, psi}$	2.94	
$+0.00002749 \times \text{Ultimate Tensile Strength, psi}$	1.73	
$+0.1695 \times \% \text{ Elongation}$	4.09	
$-0.0798 \times \text{Hardness, } R_A$	1.65	
$+0.712$ if normalized (N)	2.63	
or $+0.954$ if cold drawn (C) or warm worked (W)	2.47	
or $+1.425$ if quenched and tempered (Q)	3.27	
Limit for 95% confidence for any one term	t > 1.99	
Limit for 99% confidence for any one term	t > 2.65	
F. 104 Steels:		
1. Four Variables:		
$S_c = +9.39$		±2.20
$+3.65 \times \% \text{ C}$	4.97	
$-0.1347 \times \% \text{ Ni}$	3.06	
$-0.00001244 \times \text{Yield Strength, psi}$	1.93	
$-0.1096 \times \text{Hardness, } R_A$	3.26	
2. Best Predictive Equation Found:		
$S_c = +5.95$		±2.06
$+5.15 \times \% \text{ C}$	5.10	
$-0.602 \times \% \text{ Mn}$	2.53	
$+8.79 \times \% \text{ P}$	1.12	
$+26.04 \times \% \text{ S}$	2.92	
$-0.567 \times \% \text{ Mo}$	1.25	
$-0.1938 \times \% \text{ Ni}$	4.15	
$-0.00001053 \times \text{Yield Strength, psi}$	1.44	
$+0.0387 \times \% \text{ Elongation}$	1.24	
$-0.0753 \times \text{Hardness, } R_A$	2.14	
-0.478 if quenched and tempered (Q)	1.63	
Limit for 95% confidence for any one term	t > 1.98	
Limit for 99% confidence for any one term	t > 2.63	

critical strain, S_c. Some of these have turned out not to be useful for prediction. Thus, the best predictive equation for each class of steel tested will contain fewer than 17 variables. The computer program used was designed so that it performs the regression analysis starting with the largest number of variables, n, in this case 17, decides which variable is least significant, and then recalculates the regression for analysis using the remaining n-1 significant variables. This process is automatically repeated as far as is desired. The significance of each term is evaluated by a significance value, t. The results of these computations are shown in Table 5 for several different groupings of the alloys tested. The value of t can be related to probability by means of a statistical t-table.[8] Values of t required for 95 percent and 99 percent confidence are included in Table 5.

DISCUSSION

Questions by Merrill A. Scheil, A. O. Smith Corporation, Milwaukee, Wisconsin:

The authors have ably presented an interesting paper on the statistical analysis of corrosion cracking. It is presumed that all of the test samples used for the stress corrosion tests would be machined and therefore represent surfaces free from decarburization and other variables not consistent with the manufacturer's tubing surface. In this connection the writer would be interested to learn the effect of a layer on the exposed surfaces of the specimens of nearly carbon free iron, in the hydrogen sulfide corrosion environment. This is of particular interest in view of the fact that the authors' S_c for ingot iron, 9

TABLE 6—Effect of Tempering on S_c

Alloy Ref. No.	S_c Before	S_c After	ΔS_c
X-059C	2.2	3.2	+1.0
X-218	3.3	3.9	+0.6
X-243	2.0	3.8	+1.8
X-355A	4.8	5.7	+0.9
X-355F	3.9	5.2	+1.3
X-361	2.4	4.1	+1.7
X-378B	3.4	3.4	0.0
X-384A	3.4	3.5	+0.1
X-416B	2.1	3.6	+1.5
X-416D	3.6	3.4	—0.2
		Average	+0.88

Conditions: Molybdenum-bearing N-80 steels. Composition and mechanical properties before and after tempering shown in Table 1.

Specimens for sulfide corrosion cracking tests cuts from 3-inch long ring sections of tubing after tempering for ½-hour at 1100 F.

percent Cr stainless steel and 9 percent Ni steel would reflect a much lower susceptibility for corrosion cracking with very low or negligible carbon. The writer would also like to know whether ingot iron supposedly of very low carbon (.04 percent or less) showed negligible stress corrosion cracking susceptibility in the authors' tests.

The second question in view of the rather loose terminology of yield strength throughout the authors' data would be "Have any accurate stress strain curves been made of the various materials covered in the investigation?" If the authors used the yield strength data supplied by the vendor this value could be the yield strength noted at ½ percent stretch or the drop of the beam in testing. In order to clarify the factors applied to yield strength in the equations given by the authors it would be well to know on what basis their yield strength was determined.

Reply by J. P. Fraser:

In reply to Mr. Scheil's first question, we do not have any direct information on the effects of decarburization. Our equations show that decarburation may be harmful as regards S_c. Our data on one sample of ingot iron (Alloy Reference No. 7-152) tend to confirm this. This sample had low strength, low alloy content, and good ductility, all of which seem to favor high S_c values. However, our sample had relatively low S_c (2.1) and a reasonable explanation is that the low carbon content is responsible for the low S_c value.

All of the mechanical property data were obtained in our own laboratory, using small-sized tensile bars in a Hounsfield tensometer. Autographic stress-strain curves were obtained for each steel used. In all cases, the yield strength reported is the stress at 0.5 percent permanent elongation. Distinct yielding (i.e., drop-of-the-beam) was observed with only three of the alloys tested in the as-received condition. It may be significant that all of the tempered molybdenum-bearing N-80 steels showed a distinct yield point after tempering but not before.

Questions by D. C. McVey, Climax Molybdenum Company, Chicago, Illinois:

The authors have presented an interesting study of a complex problem. We are naturally interested in their results for molybdenum bearing N-80 pipe. It is our understanding that the composition of this grade is varied in different sizes of pipe by the producers to obtain sufficient hardenability to produce the tensile properties required by the API specification. On this basis, we would expect to find a significant variation in hardening elements and in hardenability to produce comparable properties in different sizes of pipe.

It would seem likely that a more fundamental correlation of resistance to cracking would exist with yield strength and microstructure (which are related to hardenability) than with percentages of carbon and alloying elements per se. This appears to be indicated by the improvement in resistance to cracking effected by tempering at 1100 degrees F as shown by the authors in Table 1. Hardenability of the compositions listed, when calculated (on the basis of 50 percent martensite for lack of a better criterion) by the Grossman-Field method and disregarding grain size, is significantly higher for alloy Nos. X059C, X243, and X361. These are the only steels showing a significant decrease in yield strength on tempering. They also show the largest reduction in hardness. Was any definite change in microstructure evident on tempering these higher hardenability steels? Has any of this pipe been tempered by the producers?

Another question arises with respect to all of the steels listed in Table 1. Were the compositions shown as "reported by manufacturer" ladle analyses or check analyses of the actual pipes tested?

Is there any indication of a possible relationship between residual stresses in full size pipe and resistance to cracking?

Reply by J. P. Fraser:

In reply to Mr. McVey, we agree that resistance to cracking probably is related to microstructure. However, it is difficult to characterize microstructure by any numerical code whereas the chemical composition is expressed numerically. This is one reason for not using microstructure as one variable in our statistical studies. Another reason is that we consider that the mechanism of sulfide corrosion cracking can best be explained on an electrochemical basis, with mechanical aspects of crack propagation being subsidiary to the electrochemical aspects. We have discussed this in detail in an earlier paper (see our reference 4). Therefore, we would expect the chemical composition of the steel to be as important as the mechanical properties, although of course they are intimately related.

As to Mr. McVey's question regarding the changes in microstructure on tempering, I regret that we have not examined microscopically the steels which we tempered. In addition, we do not know whether any of the pipe samples we tested were tempered by the producers. We do know that tempering of normalized molybdenum-bearing N-80 tubular goods is an accepted and often-used practice, but such a tempering heat treatment is not usually reported to the user.

The chemical compositions shown as "reported by manufacturer" in our Table 1 included some ladle and some check analyses. The suppliers of our samples were not uniform in this regard, but they did indicate that there was usually very little difference between the two analyses. As a further confirmation of the reported analyses, we made spectrographic analyses of all samples we received. If we found significant differences between the reported compositions and our analyses, we re-analyzed the sample and showed the re-analysis in Table 1.

We have no direct data which would show the relationship between residual stresses and resistance to cracking. However, a tube containing residual stresses will have lower resistance to cracking than would the same tube without residual tensile stresses, since any residual tensile stresses will add to externally applied tensile stresses.

Any discussions of this article not published above will appear in the June, 1959 issue

The Investigation of Corrosion Mechanisms
With the X-Ray Microscope*

By R. T. FOLEY*

Introduction

THE STRUCTURE and composition of the substrate metal is of extreme importance insofar as the corrosion mechanism is concerned. In order to understand better the corrosion mechanism it often is desirable to observe changes in the composition or structure of the alloy as the reaction is proceeding. The object of this report is to describe preliminary work in progress involving the use of an X-ray microscope to observe such changes in alloy structure.

The theory and operation of the X-ray microscope was described by Newberry[1] and its potential applications to surface reactions were discussed in a recent report from this laboratory.[2] In the present work a General Electric Type A5001 shadow X-ray microscope is used. The X-ray beam traverses a thickness of about 0.003 inch of the alloy under study. The details of the X-ray picture recorded on the photographic plate arise from the differences in the absorption of X-rays by the constituents of the alloy. The X-ray microscope can give the most information for those metallic systems involving two phases wherein the absorption of one phase differs considerably from that of the other. The instrument should be particularly suited to the study of re-

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actions that involve copper, iron, or zinc as segregated phases in the light alloys. The corrosion reactions first studied in this laboratory have been based on this proposition.

Magnesium-Aluminum Alloy

The first corrosion mechanism considered was the stress corrosion cracking of a magnesium-aluminum alloy (J-1). This reaction had been studied previously by Priest, Beck, and Fontana;[3] they showed quite clearly that for fine-grained specimens previous heat treatment establishes whether the failure is intercrystalline or transcrystalline. When the magnesium-aluminum alloy is furnace-cooled from 345 C, the compound $Mg_{17}Al_{12}$ is formed at grain boundaries. The presence of this compound—because it is cathodic to the alloy proper—accelerates the corrosion of adjacent metal and is responsible for intercrystalline cracking. This compound is not present in specimens water-quenched from 345 C. Samples so treated crack transgranularly; Priest et al. postulated that the transgranular cracking occurs in the crystal plane in which the Fe-Al compound is segregated. This reaction offered several advantages from the experimental standpoint. With a specific reagent, and under certain experimental conditions, the reaction is completed in

a few minutes. The specimen can be viewed for the whole duration of the reaction. The figures in this report are exposures made by looking through strips of J-1 alloy 0.003 inch in thickness.

Strips of the alloy which have been furnace-cooled from the solutioning temperature crack in an intercrystalline path when exposed under tensile stress to the chloride-chromate reagent. The X-ray micrograph shown in Figure 1 represents such a crack caught during its growth process. The nature of the cracks formed in these furnace-cooled specimens differ considerably from the cracks formed in "water-quenched" or cold-rolled specimens. The crack follows the severely pitted areas represented by the light zones in Figure 1. After observing many such sections it has been concluded that the chemical contribution (as opposed to the mechanical) is the major factor in the failure. The deep pits are mainly in the highly stressed areas. Away from the highly stressed (and cracked) areas the pitting is infrequent. It is postulated that the tensile stress is instrumental in the destruction of oxide films existing on the alloy surface allowing the corroding reagent to attack the alloy proper. Pitting occurred at an accelerated rate because of the operation of local cells, the cathode
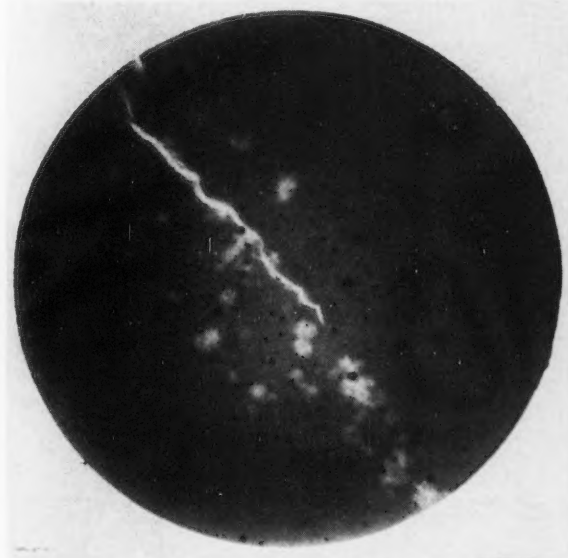
Figure 1—X-Ray photomicrograph of stress corrosion cracked magnesium alloy furnace-cooled from solutioning temperature. 50X.
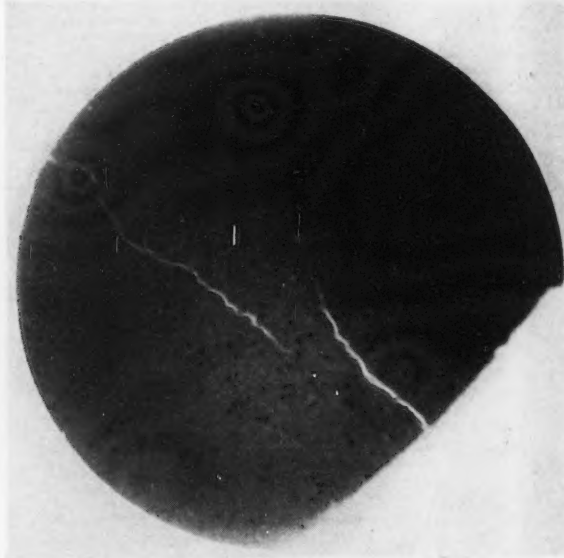
Figure 2—X-Ray photomicrograph of stress corrosion cracked magnesium alloy-water-quenched from solutioning temperature. 50X.
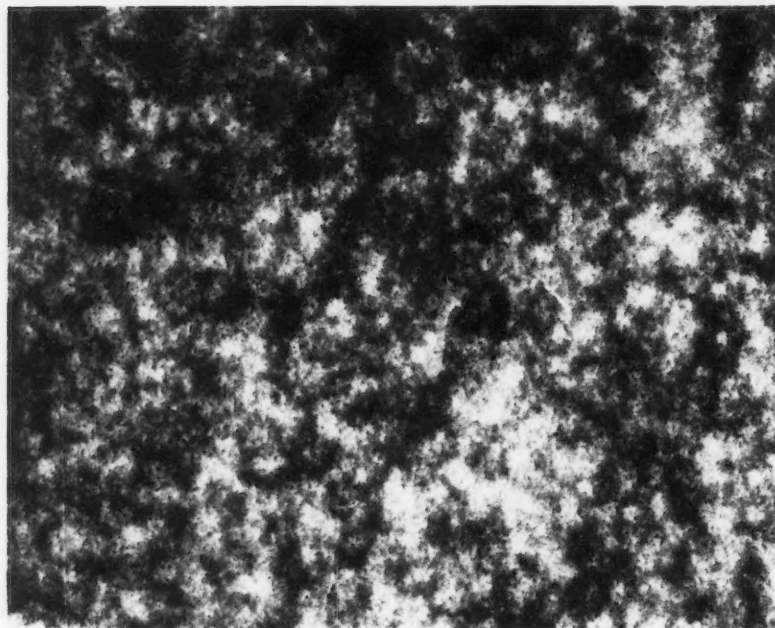
Figure 3—X-Ray photomicrograph of aluminum alloy Type 2024 after pitting. 425X.

being the $Mg_{17}Al_{12}$ compound area and the anode an adjacent solid solution. The severe attack occurred in only three minutes, resulting in a line of pits that represented an "easy path" through the alloy section.

When the alloy is water-quenched from the solutioning temperature and then exposed simultaneously to a tensile stress and corrosion reagent, it cracks transgranularly. Figure 2 is a typical X-ray view of this transgranular crack. Whereas in these samples isolated pits

are observed, they are definitely shallower and are not necessarily associated with the highly stressed—and cracked—zone. The sample pictured in Figure 2 was exposed for 5 minutes. The chemical contribution to the over-all reaction is definitely much less than that associated with the furnace-cooled specimens.

Aluminum Alloys

The second surface reaction selected for study involved the pitting corrosion

of aluminum alloys.[4] In two phase alloys such as Type 2024 and 7075 it seems to be generally accepted that accelerated pitting is due to the action of localized galvanic cells. These two alloys as well as Type 1100 were examined after immersion for 70 hours in sodium chloride solution. Only some results obtained with Type 2024 will be mentioned here. Examination of the surface after exposure with the light microscope led to the conclusion that the whole surface had been pitted in a rather uniform way. It was not possible to discern any very deep pits.

Figure 3 is an X-ray photomicrograph of a section of a 2024 alloy specimen at high magnification designed to show the relationship of the second phase (dark areas) to pits (light areas). It is very informative to examine these specimens with stereo-photography (three-dimensional viewing). One is impressed by the tremendous roughness of the surface which is covered by the openings of small pits. Once underneath the surface these pits follow devious paths. The effect is one of tunneling rather than direct penetration. The dark segregated areas in Figure 3 are $CuAl_2$ compound which is unattacked. The structure remaining after pitting thus resembles a skeleton composed of copper-rich material. These views are good demonstration of the classical concept of localized cell action but one must adopt a new viewpoint in considering the significance of "pit depth."

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3. D. K. Priest, F. H. Beck, and M. G. Fontana. *Trans. ASM*, **47**, 473 (1955).
4. For recent work in this field see P. M. Aziz. *J. Electrochem. Soc.*, **101**, 120 (1954); P. M. Aziz and H. P. Godard, *ibid*, **102**, 577 (1955).

Any discussions of this article not published above

will appear in the June, 1959 issue

Cathodic Protection of a Gas Distribution System*

By EDWARD F. FOWLER

Introduction

THE TITLE of this paper would imply that the material contained herein could be used as a criterion for gas system distribution protection. It might be well to point out at the outset the information contained therein is based solely on the experiences of the author's own company. It is not the author's purpose to outline the various methods which may be used to apply cathodic protection to distribution systems, but rather to describe in detail the method used by Northern Illinois Gas Company. Although much of the material is generally accepted as standard for the application thereof, it is felt that with the volume of work that has been done by this company, some of the short cuts and operation procedures may be of value to companies starting such a program.

Northern Illinois Gas Company began its operation as such on February 1, 1954. Prior to that date, it was part of the Public Service Company of Northern Illinois, a Division of the Commonwealth Edison Company. It serves almost 600,000 customers residing in 260 communities, having a popu-

About the Author

EDWARD F. FOWLER attended the University of Illinois Engineering School and has since been with the Northern Illinois Gas Company or its predecessors. For the past 22 years, he has been in Operating and Engineering Departments, with the past six years being in Corrosion Control.

Abstract

The manner in which a gas company applied cathodic protection to its gas distribution system is described. Topics discussed include setting up a basis for current requirements, analyzing of cathodic protection work orders, engineering of cathodic protection for new installations, protection of replacements of pipe, and cathodic protection of a town as a unit. The coordination work done between various sections of the company in applying cathodic protection are outlined. A number of typical work forms used in the company cathodic protection program are reproduced.   5.2.1

lation of more than two million people. Figure 1 shows this 10,000 sq mile area which is located outside of the city of Chicago, and includes its rapidly expanding suburban territory. This expansion is reflected in the fact that more than 37,000 new services, were installed during the past year. The system includes approximately 43 million feet of main varying in size from ¾" to

48", plus the service pipe off this main. Included in this system is more than 7 million feet of cast iron pipe. Generally the cast iron is located in the older part of the system and is normally the low pressure portion. The steel or high pressure system has borne the brunt of the expansion and quite naturally has the priority in the corrosion control program. However, the cast iron is not entirely neglected as the services off the cast iron system are steel.

The author's company and its predecessor companies have been actively engaged in the program of corrosion control as is evidenced by the fact that coating and wrapping has been used on steel pipe since 1930. The benefits of cathodic protection were not evident at that time so, just half a job was done
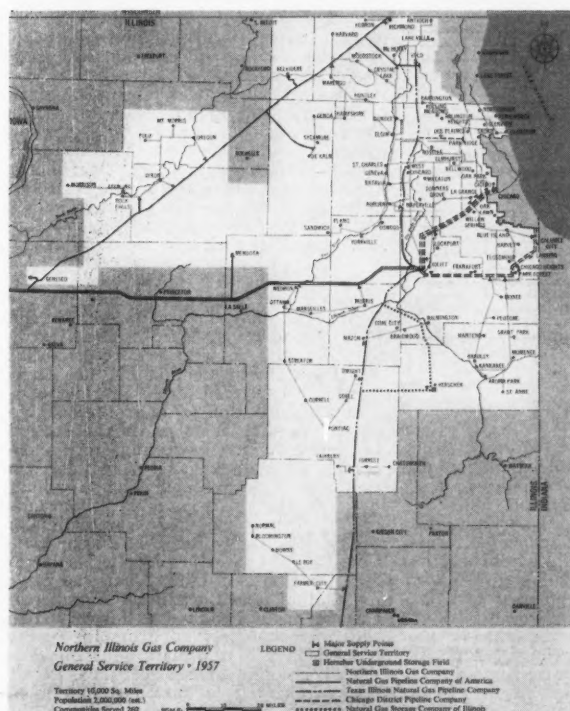
Figure 1—Northern Illinois Gas Company territory map.
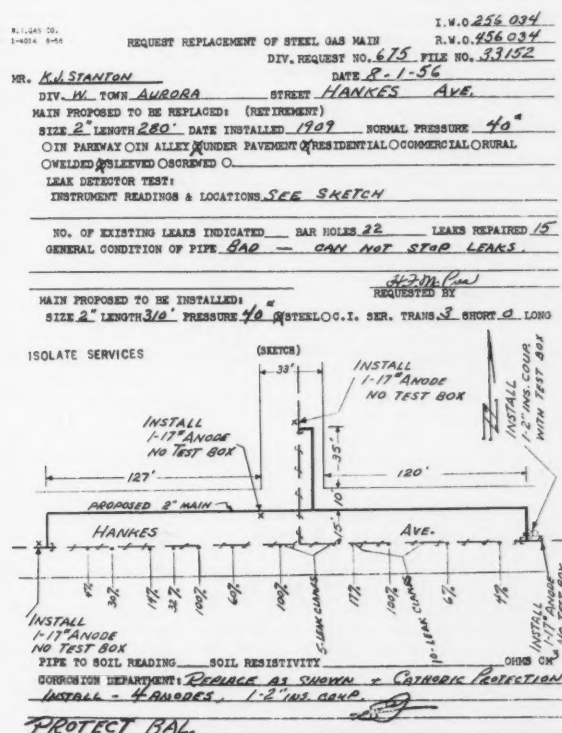
Figure 2—Gas main replacement request.

Figure 3—Atlas page.

Figure 4—Test point log sheet.

tions, it was found practicable to make some assumptions, and avoid excessive engineering expense. In other words cathodic protection of new installations possibly could be over-engineered. The work load in the Corrosion Section in the past five years has included approximately 3000 separate jobs per year. To have made detail studies of each job would have taken a corps of engineers plus transportation. Therefore, as a short-cut, it was assumed that voids and poorly coated joints on new coated and wrapped steel pipe would amount to approximately 2 percent of the surface area and, 3,000 ohm per cm^3 was taken as the average soil resistance. The results prove that the engineering economy was justified since less than 2 percent of the installations resulted in excessive or inadequate protection.

The distribution system is of many types and ages, with the presence of a considerable amount of old pipe in service. The protection of this old steel pipe is based on using 100 percent bare factor on all steel pipe installed prior to 1930 with graduated percentages being used from 1930 to 1950. Since then all new steel pipe installed has been coated, wrapped, and cathodically protected.

Having adopted this rule of thumb, the next step is to specify the cathodic protection. This is done by reviewing the work order for each proposed main extension. To do this, all work orders are routed through the Corrosion Section of the Engineering Department. In order to analyze these work orders, the Corrosion Section has a complete set of atlas maps. These maps are duplicates of the ¼ Section and 1/16 Section maps used by The Engineering Department, and are drawn on sheets 21½" x 17" to a scale of 1"-200' and 1"-100'. Indicated on the maps are the location, the size, and the type of existing main. For use in corrosion control, these atlas maps have been reduced to one half size and are printed on 8½" x 11" vellum paper, which allows filing in loose leaf books and simplifies reprinting of the sheets.

All installed anodes, insulating features, and test points are recorded on these reductions by use of codes or symbols. In addition to the atlas map record of corrosion control, log sheets are filed with these maps. On these log sheets each test point is recorded showing the type, the location, the date installed, and the pipe to soil readings.

New System Installations

The engineering of cathodic protection for new installations is done in the following manner. The preliminary sketches and layouts are received by the Distribution Section of the Engineering Department from the local Division organization. This group has prepared accurate sketches of the section or streets involved, varying from short extensions of less than 100 feet for one customer to entire subdivisions for hundreds of customers involving thousands of feet of new main. On completion of the field work by the Distribution Section, the sketch showing tie-ins, sizes and locations of mains, various valve installations and the ultimate number of services to be installed, is forwarded to the Corrosion Section. From the length and the size of the main, plus the estimated amount of service pipe, at 70 feet per service, a current requirement estimate is made. By reference to the atlas map, all previous installations are reviewed and proper corrosion control

until a program for cathodic protection was put in effect.

Corrosion Organization

In 1942 the company installed the first cathodic protection unit on a main that was in a very high stray current area. From a study of the benefits of this installation, another unit was installed on a section of main which was about ten years old. After analyzing the results, it was decided that a cathodic protection program would be initiated. In 1945, a corrosion control organization was set up, and program was presented to the management that provided for the application of cathodic

protection to all new coated and wrapped installations, all existing main supply systems and, eventually, protection to the complete system. This organization is a section of a centralized engineering department which performs all of the engineering functions of the company.

The first step in applying cathodic protection to the system was to set up a basis of current requirements. In the early years of the activity, quite an effort was made to conform to engineering practices by obtaining a lot of detail, such as information relative to soil resistance, etc. But, from the data obtained on a large number of installa-

recommendations indicated on the sketch.

Following the issuance of the order and the installation, a copy of the completed sketch is forwarded to the Corrosion Section so that necessary checks to ascertain the conditions of the installation may be made. In an era of large expansion, it is quite an assignment to get all tests made. It is important, however, that provisions be made for immediate inspection of an installation so that corrective measures may be taken before the order is closed out and forgotten.

Maintenance and Cathodic Protection

In addition to designing corrosion control for new main extensions, the protection of all replacements of pipe must be considered. This is by no means a simple job, as the adjoining pipe is as variable as the system itself and requires careful consideration. The protection of the old or existing pipe, in conjunction with a replacement often presents a problem, which involves isolation of the main and services plus separation from all underground structures. In many instances the Corrosion Section is called to inspect exposed main for which a replacement is desired. This inspection involves pipe to soil readings, soil resistivity, pit depth, and general location and condition of the main, which helps in arriving at a decision whether the main should be replaced and cathodically protected, or the leaks repaired and cathodic protection installed to extend the life of the main. The justification of main replacements has too many variables to go into at this time, but is mentioned to show it is included in the corrosion control work.

The application of cathodic protection to replacements is done by a method similar to that used in protecting main extension; however, on occasions, it is desired to protect not only the new main but part of the adjoining or existing main. This is done by cutting in an insulating feature at the tie-in or on the old system some 2,000 feet to 3,000 feet back of the new main. Any such installations are indicated on the work order as part of the corrosion control recommendations, and an order is issued for anode installation on the old main and isolation of services off this main at the meters. To clarify this procedure, the processing of a typical replacement request will be followed to completion.

Figure 2 shows a request indicating proposed main replacement. A sketch on this request shows the existing main in broken lines and the proposed main in solid heavy lines. After this request is checked against the existing anode installations shown on the atlas page seen on Figure 3, which is part of the atlas showing this particular job location and the cathodic protection code, corrosion control is planned accordingly and indicated on this request. It is then sent to the Engineering Department where it is field checked and drafted. It is returned to the Corrosion Section for a complete check before being sent to the Division for construction work.

The Division returns a completed work order showing corrected location measurements of installed main, anodes, and insulating features. This copy, sent from the Division to the Corrosion Section, is checked and the pipe to soil readings desired are indicated on the completed work order by a rubber

Figure 5—Work order for cathodic protection.

stamp. The order is then filed in the active files for the pipe to soil readings to be made. The Corrosion Section personnel make all first readings and record the resultant readings on the log sheet accompanying this atlas page. This log sheet is seen on Figure 4.

Figure 5 shows the work order made up to protect the old main in connection with this particular request. The installation of anodes to protect the old main on this type of a job is done by the corrosion crew, and the work order is returned completed to the Corrosion Section. Pipe to soil readings are then taken and logged. If these readings indicate a pipe to soil change of negative 0.3 of a volt to the normal unprotected pipe to soil readings, this section is considered protected.

A second reading is made of all test points one year after the date of installation. This is done by Division personel. To coordinate this second reading with the Corrosion Section studies, printed copies of reduced maps and log sheets are sent to the Division for readings, after which they are returned to the Corrosion Section. In some instances, after a study is made of a unit,

it is necessary to install additional magnesium anodes to give adequate protection.

Occasionally, low pressure systems are converted to high pressure systems. All such conversion work is designed by the Planning Section of the Engineering Department, and the work order is routed through the Corrosion Section where corrosion control is indicated. It is a company policy to test all services to be converted by cutting the service at the main and subjecting it to an air pressure test. During this test, house regulators are set and services are isolated at the meters. Anodes are installed at this time on the services as indicated on the conversion work order. In addition to service testing, all leaks on mains are repaired before the conversion, and the pipe exposed is inspected by the Corrosion Section personnel. Pipe to soil readings, soil resistivity, and so forth, are made to enable revision of recommendations if more current is desired. The tie-in to high pressure is isolated from existing high pressure if necessary, and the cut-off from low pressure is physical.

In some of the smaller towns it is

G.C.S. 610.01 TO G.C.S. 610.03
SUPERSEDES G.C.S. 610 01 TO 610 03   11-21-50

PUBLIC SERVICE COMPANY

METER INSTALLATION
60-POUNDS MAXIMUM REGULATOR INLET PRESSURE   4-30-53

TINNED CASE METER, WITH REGULATOR

G.C.S. 610.01 — 5-LIGHT   G.C.S. 610.02 — 10-LIGHT   G.C.S. 610.03 — 5-LIGHT, DOUBLE

FRONT VIEW ⑤   FRONT VIEW ⑤   SIDE VIEW   FRONT VIEW

NOTES
① INSTALL WITH TAIL PIECE AND INSULATING GASKET DOWNWARD
② END OF VENT PIPE SHALL BE IN AN OPEN AND EXPOSED LOCATION AT LEAST 12" ABOVE FINISHED GRADE, PREFERABLY NOT UNDER A WINDOW HORIZONTAL LENGTH OF VENT PIPE MUST NOT EXCEED 15 FEET UNLESS APPROVED BY OPERATING DEPARTMENT SUPERVISOR
③ FOR DETAILS OF SERVICE PIPE FROM THIS POINT TO MAIN SEE GCS 330.2
④ CUSTOMER TO PROVIDE FUEL RUN, ADEQUATELY SUPPORTED
⑤ SIDE VIEW SIMILAR TO GCS 610.03
⑥ ALTERNATE POSITION

LOC	MATERIALS REQUIRED	QUANTITY 610.01	610.02	610.03	GMS NO
A	¾" X 2" NIPPLE	1	1	1	
B	¾"-90°- STREET ELL	4	3	7	302
C	¾" SERVICE REGULATOR- VERTICAL CONNECTIONS	1	1	1	801 01
D	¾" X 3" NIPPLE	4	4	4	
E	¾" SCREWED INSULATING UNION	2	2	2	315 6
F	¾" BARE STEEL PIPE	AS REQ			
G	¾"-90° SCREWED ELL	2	2	2	301
H	¾" VENT CAP	1	1	1	
J	¾" X 6" NIPPLE	1	1	1	
K	¾" CLOSE NIPPLE	1	1	3	
L	¾" METER COCK	1	1	2	
M	¾" X 26½" BARE STEEL PIPE, THREAD BOTH ENDS	0	0	1	
N	¾" SCREWED TEE	0	0	1	303
O	5-LIGHT METER BAR	1	0	2	
P	5-LIGHT METER SWIVEL WITH NUT AND WASHER	2	0	4	
Q	5-LIGHT TINNED CASE METER	1	0	2	
R	¾" SCREWED RED ELL	0	1	0	309
S	1" X 2" NIPPLE	0	1	0	
T	10-LIGHT METER BAR	0	1	0	
U	10-LIGHT METER SWIVEL WITH NUT AND WASHER	0	2	0	
V	10-LIGHT TINNED CASED METER	0	1	0	
W	¾"-45° SCREWED ELL	2	2	2	305

Figure 6—Specification for service isolation.

GCS 430.1 TO GCS 430.2
SUPERSEDES G C S 430 1 TO 430 2   7-26-56

NORTHERN ILLINOIS GAS COMPANY

SERVICE REGULATOR INSTALLATION
60 PSIG MAXIMUM INLET PRESSURE   1-7-57

OUTDOOR INSTALLATION OF ¾-INCH REGULATOR

GCS 430.1 — OUTLET PIPE ABOVE GRADE - PREFERRED   GCS 430.2 — OUTLET PIPE UNDERGROUND - ALTERNATE

PLAN   DETAIL NO.1   PLAN

SEC. X-X   SEC. Y-Y

NOTES
① FOR DETAILS FROM THIS POINT TO MAIN SEE GCS 330.3 OR GCS 320.3
② INSTALL REGULATOR AT LOCATION PRESCRIBED IN GCS 305.06 OR GCS 301.11 TO GCS 310.15. PAINT REGULATOR AND FITTINGS WITH RUST PREVENTIVE PAINT
③ INSTALL GAS TIGHT CASING THROUGH WALL (GCS 302.01 TO 302.05) EXCEPT IF THERE IS NO AIR SPACE WITHIN WALL, CASING MAY BE OMITTED. COVER CARRIER PIPE WITH COATING TAPE UNLESS IT PASSES THROUGH CASING ABOVE GRADE. CALK CARRIER PIPE INTO CASING ON WALL WITH JUTE PACKING & FILL REMAINING SPACE WITH NON-SHRINKING CEMENT OR PORTLAND CEMENT GROUT.
④ ¾" IS MIN SIZE INSTALL SIZE SPECIFIED ON ORDER FOR INSTALLATION, IF THAT SIZE IS LARGER. FOR BUILDING WITHOUT BASEMENT, PIPING FROM THIS POINT DOWNSTREAM SHALL CONFORM TO GCS 310.31 OR ANOTHER APPROPRIATE SPECIFICATION FOR INSTALLATION OF LOW PRESSURE SERVICE PIPE.
⑤ INSTALL SO THAT RISER WILL BE AS CLOSE TO WALL AS PRACTICABLE.
⑥ IF CUSTOMER HAS PROVIDED BUILDING SERVICE (GCS 954.1) OR ENCLOSED METER LOCATION (GCS 953.6) INSTALL PIPING DOWNSTREAM FROM THIS POINT AS SHOWN IN DETAIL NO.1 FOR ENCLOSED METER LOCATION TURN OUTLET PIPE CLOCKWISE 270° TO ALTERNATE POSITION SHOWN IN PLAN. SEE NOTE 11
⑦ ALTERNATE POSITION FOR PIPE ENTRANCE INTO BASEMENT
⑧ FOR DETAILS FROM THIS POINT DOWNSTREAM SEE SPECIFICATIONS FOR METER INSTALLATIONS GCS 610.04 AND FOLLOWING
⑨ BROKEN LINE INDICATES FACE OF SIDING FOR FRAME WALL
⑩ ALTERNATE POSITION WHEN ENTRANCE IS NOT IMMEDIATELY BELOW REGULATOR INSTALLATION. SEE SECTION X-X, NOTE 6.
⑪ CENTER LINE OF ALTERNATE POSITION FOR ENCLOSED METER INSTALLATION. SEE SECTION X-X.
⑫ FOR DETAILS OF RESIDENTIAL BUILDING SERVICE SEE GCS 954.1 FOR DETAILS OF ENCLOSED METER INSTALLATION SEE GCS 610.24 TO GCS 610.27 OR GCS 610.34 TO GCS 610.37
⑬ DOES NOT APPLY IF METER IS TO BE INSTALLED AT READING WINDOW

* LATEST REVISION

LOC	MATERIALS REQUIRED	QUANTITY 430.1	430.2	GMS	LOC	MATERIALS REQUIRED	QUANTITY 430.1	430.2	GMS
A	1" X ¾"-90° RED. STREET ELBOW	1	1	310	M	¾" BARE STEEL PIPE	AS REQ		
B	¾"-45° SCREWED ELBOW	AS REQ	1		N	¾" SCREWED CAP	1	1	307
C	¾" X 2" NIPPLE	2	2	801 01	P	RUST PREVENTIVE PAINT, SUBALOX #50B OR EQUIVALENT	AS REQ		
D	¾" SERV REG VERT CONN	1	1		Q	NON-SHRINKING CEMENT, OR	AS REQ		
E	¾" X 3" NIPPLE	*2	*2	302		PORTLAND CEMENT AND SAND	AS REQ		
F	¾"-90° STREET ELBOW	*3	*3		R	PIPE COATING TAPE	AS REQ		
G	¾" SCRD INS UNION	*AS REQ	0	315 6	S	¾" X 4" NIP OR LENGTH TO FIT	AS REQ		
H	¾" X 2" NIP OR LENGTH TO FIT	AS REQ	1		U	¾" SCREWED UNION	AS REQ	1	
J	¾"-90° SCRD ELBOW	AS REQ	2	301	V	¾"-90° BUTT-WELDING ELBOW	0	1	
L	¾" VENT CAP	1	1		W	JUTE PACKING, NOT TARRED	AS REQ		

Figure 7—Specification for service regulator installation.

advisable to protect the town as a unit. This is done as follows:

First, the patrolmen are given a complete set of atlas sheets for the area to be protected which show the date of main installation and the location of the main. A complete leakage survey is made of all main and service pipe installed prior to 1940. The patrolmen record on this set of atlas sheets all leak indicator readings.

Second, Division personnel with Corrosion Section personnel record on these atlas sheets all repaired leaks from leak tickets on file. This check of leaks repaired on the main may indicate that a survey of some pipe installed after 1940 should be made. If so, the patrolmen complete this survey and record all leak readings on these atlas sheets.

Third, the area is studied by the Planning Section of the Engineering Department, and the ultimate pipe size requirements are indicated on these sheets.

Fourth, a replacement request is made up to replace the sections of bad pipe and undersized pipe.

Fifth, a plan for cathodic protection is made.

Sixth, an order to isolate all services in this area is issued and the contruction work is started.

Seventh, the installation of anodes and insulating features is started in connection with the main and service replacement work, at which time the Corrosion Section personnel make an inspection of pipe exposed, and make any required revision of anode installations.

Eighth, concurrent with, and on completion of anode installation, pipe to soil readings are taken and studied to ascertain the degree of protection achieved.

In addition to this planned method of protecting distribution systems, hot spot protection programs have been initiated. This consists of installing magnesium anodes at the time leaks are repaired on existing steel mains and services. Of course, all this type of work is done on a maintenance ticket by the maintenance crew. In the most part, these tickets are made up from leak surveys prepared by patrolmen. In the event the leak reported is not of an emergency nature, the ticket is filed in the Division active leak file, which allows the Corrosion Section personnel an opportunity to review a number of leak tickets, and indicate on the ticket the type of anode installation desired.

Instructions for the installation of magnesium anodes in connection with leak repair and maintenance work are issued to each crew leader, assuring that a magnesium anode will be installed at the time a leak is repaired on the steel main or service. On completion of the work on these maintenance tickets, the tickets are sent to the Corrosion Section, and each 17-lb. anode is recorded on the reduced atlas sheet. If a test box has been installed, the location of the test box is logged.

The problem of stray electric railway current mitigation is a serious problem. With three electrified railroads passing through the territory, a great deal of time, effort, and money was spent in effecting proper control through the installation to switches and drain cables. The majority of the drainage is done with the polarized relay type of switch although some drainage is done through carefully protected selenium stacks.
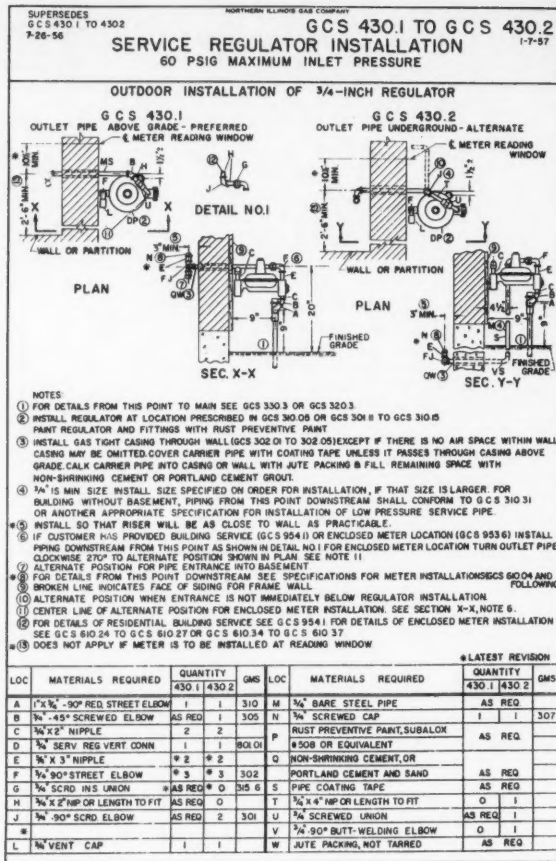
Discussion

Service isolation was one of the first items of consideration for application of cathodic protection to the system. So along with gas main protection, service isolation was begun in 1948. Prior to 1950 both the regulators and meters on services off the medium and high pressure steel system were located in the basements, or in a location with protection from freezing temperatures. As seen on attached specification (Figure 6), this type of service has the insulating feature, currently an insulating union, installed on the riser to the meter. It is adjacent to the regulator and on the regulator vent. In 1950 specifications were changed for regulator installations after which time they were installed outside close to the building at the service entrance. This is shown on Figure 7. The meter remains on the inside of the building with the isolation ahead of it. This outside regulator location also affords many more test points, thereby eliminating the locating and upkeep of test locations over or near the main.

Figure 8—Specification for service pipe installation.

Figure 9—Specification for rectifier installation.

Figure 10—Specification for ground bed installation.

Figure 11—Specification for anode installation.

Also since the service entrance into a building is of great concern corrosion-wise, the use of the regulator as a test point gives additional data for full system protection coverage.

The most acute problem is that of improper testing for isolation of services. Each man who sets meters and regulators is furnished with proper instructions and test lights to test the effectiveness of the insulator. However, unless this is done properly at the time of installation, one shorted service invariably makes large areas of cathodic protection application ineffective. With the knowledge that this does occur, and the enormous amount of work involved in locating the short, an insulating fitting tester has been developed to test in place such fittings. Details of this tester will be presented at a later date.

On steel services off cast iron main specifications call for isolation at the main and inside the building with a 1-lb bare magnesium anode at a selected location. This is shown in Figure 8. The initial insulating fittings at the main were mallable, but in the last few years a brass fitting with an insulating feature on it has been used. The 1-lb magnesium anode initially was installed with backfill but following actual consumption data in comparison to 1-lb bare anodes it was found that the bare anode actually gave longer life—16 years to 35 years. This is assumed to be due to the presence of a higher environment resistance with the bare anode. This tends to decrease the loss of metal normally encountered where the environment is a low resistant and the current density is low (as will be found on coated and wrapped services.) Actually some current checks showed less than one milliamp on an average 70 foot, service.

Protection of inter-city connecting mains or principal supply mains is also a problem. Quite a large percentage of these mains are bare or with coating of questionable condition. Therefore, approximately 90 percent of these mains are protected with rectifiers. This type of protection was chosen as an expedient, as well as to eliminate some installation difficulties encountered in anode application on well-traveled highways. Specifications for rectifier and ground bed installations are shown in Figures 9 and 10.

The normally accepted practice of locating the ground bed in the lowest soil resistance area available, has been followed consistently. Also in some of these rectifier installations an old smaller abandoned main that paralleled the existing main was used as the ground bed. One such installation has a ground bed eight miles long. This has proven very economical.

A note as to the installation of anodes may be of interest at this point. Anodes are installed on new pipe by the Construction Department at the time the main is laid, but rectifier ground beds and magnesium to protect the existing or older pipe are installed by the Corrosion Section four-man crew. They are equipped with a flat bed truck, having an independent engine driven auger with wiggle-tail features capable of digging a 14" hole 12-feet deep. They also have a street type truck with all necessary tools for any situation including a compressor, winch, and large water storage tank for wetting and puddling in anodes. The normal installation on existing main is done by augering a hole 12 feet deep, close to the main. The main is exposed for attachment of anode wire by sloughing off the earth. The spot for the thermite weld is cleaned off with scrapers and an air operated grinder. The thermite mold with special wire holding attachment and long handle is placed and fired with a hose torch. After cleaning and testing the weld it is covered with mastic coating and protective paper. All of this installation is done from ground level.

The economy of such an installation is seen when compared to the conventional method of making a large excavation for main exposure and ditching from the main for placement of the anode. Details of this are shown in Figure 11. Installing anodes in a hole 12 feet deep gives excellent results because the anode is in earth having a more permanent moisture.

Conclusion

In conclusion, it should be added that 35,000 magnesium anodes of 50, 32, 24, and 17 lb size have been installed. In addition some 109 rectifiers and 17 drainage switches are in operation. With these installations, more than 15 million feet of main plus the service piping off this main have been protected. This year, more than 15,000 17-lb magnesium anodes will be installed as well as about 40,000 insulating fittings at the meters. By continuing this method, it is anticipated that the entire steel distribution system will be cathodically protected within the next ten years.

Any discussions of this article not published above will appear in the June, 1959 issue

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TECHNICAL PAPERS ON CORROSION WELCOMED

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

Comparison of Corrosion Engineering Or Materials Engineering Functions In Various Chemical Plants*

By L. W. GLEEKMAN*

IN THE COURSE of an annual report on the accomplishments of the Wyandotte Chemicals Corporation's Materials Engineering Group, data comparing materials engineering or corrosion engineering groups in several other chemical companies were amassed. This information is presented for general information in Table 1 where the comparison of 16 chemical companies is shown. This is done in terms of: (1) In what department or division the materials engineering or corrosion engineering group is located; (2) The size of this group in terms of the number of engineers and technicians; (3) The method by which the various companies charge group time; (4) The scope of group activities in terms of eight general categories; and (5) Whether or not an annual evaluation of economic savings is made.

No formal conclusions can be drawn from this table since there are obvious variations among the 16 companies. Such variations include the number of plants within the corporation, their location, the chemicals manufactured by these plants, the age of the plants, the type of construction, and the very age of the materials engineering group within these companies. However, the over-all chart does serve a useful function by which other chemical concerns may wish to compare their materials or corrosion engineering groups with the 16 companies represented.

Since many of the companies are divisions of major corporations, it was not

Abstract

Tabular information is given to show how 16 chemical companies organize and operate their corrosion engineering groups. Information given for each company includes name of the department in which materials engineering or corrosion engineering group is located, size of this group in terms of number of engineers and technicians, method of charging time, scope of group activities in terms of eight general categories, and information regarding annual reports on evaluation of economic savings.   1.7.1

TABLE 1—Comparison of Corrosion Engineering or Materials Engineering Functions in Various Chemical Plants (As of May, 1958)

Company and Location	Location of Mat. Eng. Group	Size of Mat. Eng. Group — Total Eng'r.	Total Tech.	Method of Charging Time	Carry-out Metallurgical Investigations	Recommend Repair Materials & Methods	Investigate Paint Problems	Run Laboratory Corrosion Tests	Run Field Corrosion Tests and Surveys	Consult on Design of New Plants	Recommend Internal Coatings	Conduct Non-Destructive Plant Tests	Evaluaton of Economic Savings
Wyandotte Chemicals, Wyandotte, Michigan	Development Dept, Research & Eng Division	3	1	Directly to Projects	X	X	X	X	X	X	X	X	Yes, annually
Diamond Alkali — Cleveland, Ohio	Central Eng*	1	...	Overhead1 + Projects	X	X	X		X	X	X		When required
Painesville, Ohio	Technical Service	1	...		No	X	X	X	X	X	X		
Houston, Texas	Engineering	½	...		No	X	X	X	X	X	X	X	
Hooker Electrochemical, Niagara Falls, N.Y.	Research (including 2 men in operation)	3	2½	Directly to Projects + Overhead	X	X	X	X	X	X	X	X	Yes—when requested
Columbia-Southern, Barberton, Ohio	Maintenance Eng	2 (plus Corrosion Chemist in Research part time)	1	Overhead	X	X	Also Lubrication & Inspection (Audigage)				X	X	Yes—first time
Corpus Christi, Texas	Technical Director	1	1½		X	X	X	X	X	X	X		
New Martinsville, W. Va.	Research Lab	1			X	X	X	X	X	X			
Lake Charles, La.	Engineering	1			Corrosion Engineers meet informally at least once a year to interchange data—quarterly reports circulate				X				
Monsanto Chemicals, St. Louis, Mo.	Corrosion Section, Engineering Dept, R. & E. Division; (Corrosion liaison men in all plants)	4 (+ 1½ Staff men in Corrosion Information Center)	4	Mainly Overhead	X full time	X	X full time	X	X All plants	X	X	X	Not required but presented
					Does own work in area of technological development—work usually originates by request								
Dow Chemicals, Midland, Michigan	Maintenance	7	3	Overhead	X	X	X	X	X	Liaison with Eng'r.	X	X	Yes—regularly
Freeport, Texas	Partly in Research and partly in Maintenance	8		Overhead	Personnel specialize by nature of work — X	X	X	X	X	X	X	X	Yes

TABLE 1—Continued

Company and Location	Location of Mat. Eng. Group	Size of Mat. Eng. Group — Total Eng'r.	Size of Mat. Eng. Group — Total Tech.	Method of Charging Time	Carry-out Metallurgical Investigations	Recommend Repair Materials & Methods	Investigate Paint Problems	Run Laboratory Corrosion Tests	Run Field Corrosion Tests and Surveys	Consult on Design of New Plants	Recommend Internal Coatings	Conduct Non-Destructive Plant Tests	Evaluation of Economic Savings
Union Carbide Chemicals, Texas City, Texas	Process Development	2	1	Overhead	X	X	N?	X	X	X	X	No	
South Charleston, W. Va.	Engineering Dept	1		Overhead	X	X	X	X		X	X	Some	
	Process Dev. (Res)	5	3	Overhead		X				X	X		
Institute, W. Va.	Engineering Dept	1		Overhead	Some	X		Some	X	X			
Solvay Process Division, Allied Chemical & Dye, Syracuse, N. Y.	Research	2 (including Metallurgist in Eng'r.)	1	General charge order for corrosion + charged directly to plants	X	X on large $ problems	Not Now	X	X	X (minor)			No great detail involved
Westvaco Chlor-Alkali, South Charleston, W. Va.	Engineering	2		Overhead	No	X inc. insp.	X	X (minor)	X	X on design committee	X	X	No
Penn Salt Mfg. Co. Philadelphia, Pa.	Central Eng (Maint. Section) for all plants*	1 (Part Time)		75% as overhead + 25% directly signed to plants	No	X	X	No	X	X (major)	No	No	Yes, separately for each specific application
				(Plus 12 full time on paints, coatings and cements)									
Wyandotte, Mich.	Engineering by Plant Eng Groups at other locations			To plant directly	No	X	X	No	X	No	X	X	
Stauffer Chemicals, Chauncey, N.Y.	No Corrosion Group	(Work in the Materials Eng category is handled by plant know-how or by Process Development)			No	1	2 (These categories by experience)	3				1	
E.I. duPont, Wilmington, Delaware	Engineering Dept*	24		Directly Assigned	X	X	X	X	X	X	X	X	Yes
General Aniline & Film Corporation, Linden, N.J.	Process Eng	2 (+ part time activity at various plants)	0	Directly to Projects	4	X	X	No	X	4	X	X	When requested
General Chemical Div, Allied Chemical & Dye, Camden, N.J.	Central Eng*	5	2	Directly to projects or to Engineering; overhead for work with plant maint.	X	X (Coordinates Research, Pilot Plant and Plant Engineering Corrosion Work)	No	X	X	X	X	X	Recorded but not currently reported
Celanese Corporation of America, Charlotte, N.C.	Engineering or Maintenance Eng. (corrosion and inspection activities usually combined)	14 at 9 plants	11	Overhead	X	X	X	X	X	X	X	X	Yes
American Cyanamid: New York, N.Y.	Eng. and Construction Division	1		Projects and Overhead	X	X	X	X	X	X	X	X	Yes
Stamford, Conn.	Research Division	1		Projects	No	X	No	X	No	No	X	No	No
Bound Brook, N.J.	Engineering	1	1	Projects and Overhead	No	X	X	X	X	No	X	X	
Lederle, Pearl River, N.Y.	Engineering	⅓		Projects and Overhead	X	X	No	X	X	X	X	No	Yes
Fortier, La.	Technical Dept.	1	2	Projects and Overhead	X	X	No	X	X	No	Aids	X	

¹ By request
² By research or plant labs
³ By plant depts
⁴ Limited
*Consultant to all company plants

considered feasible to correlate the size of the materials engineering group with either the annual sales of the company or the number of employees; this information was not available for several of the companies represented. It is felt that a separate story could be written for each company concerned as regards why they function as they do, the historical factors regarding their present location, the advantages and disadvantages of their size, method of functioning, scope of activities, etc. That, however, is beyond the purpose of this comparison.

Any discussions of this article not published above will appear in the June, 1959 issue

Limitations on Chemical Means
Of Controlling Corrosion in Boilers*

By DOUGLAS E. NOLL

Introduction

THE SUBJECT of corrosion in boilers, particularly those in high pressure power plants where relatively pure water is used, has occupied many pages in technical journals. However, in spite of the many man-hours expended in investigating the causes and solutions of corrosion problems, boiler plant operators still experience tube failures. This does not mean that research has been in vain or that the problem of corrosion is an insoluble one. Actually, the problem is being solved over and over again. As long as there is technological progress that permits ever increasing boiler pressures, temperatures, and ratings, corrosion in boilers will continue to be a problem.

Temperature, of course, can never be divorced from the problems of corrosion. As pressures go up and as tube metals become hotter, temperature becomes an increasingly important factor. The relationship between temperature and corrosion is more than just qualitative; the corrosion mechanism may actually differ at different temperatures. This relationship has been investigated rather extensively recently to learn what happens in the primary loop of pressurized water nuclear power plants. This investigation provides the basis for a new way of looking at boiler tube corrosion to be discussed later.

Examples of Tube Failures

Corrosion in boilers can be attributed to numerous causes. In many instances there is a chemical solution to the problem. Four types of corrosion will be discussed briefly.

The type of corrosion attack sometimes found in boiler economizer and downcomer tubes when there is a significant amount of oxygen in the feedwater is shown in Figure 1. This problem is not as prevalent as it once was, thanks to the efficient operation of modern deaerating heaters. The number of recent papers dealing with chemical oxygen scavengers indicates that this problem still exists for the operator and water chemist.[1,2,3]

Figure 2 represents an example of corrosion beneath deposits of iron oxide and copper carried into the boiler from the condensate and feedwater systems. The damage noted here has nothing to do with galvanic action set up between the copper in the deposit and the tube metal but is the result of the inability of boiler water to rinse the surface beneath the deposit. In the pores of the deposit, boiler water solids concentrated and dissolved the iron oxide layer that normally protects the

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steel from the action of boiler water. Although very high concentrations of sodium hydroxide are particularly destructive to the iron oxide layer, the presence of free caustic in the boiler water is not a requisite for this type of attack.[4] Obviously the best approach to this problem is to reduce corrosion in the condensate and feedwater lines by the use of neutralizing or filming amines.[5,6,7]

Figure 3 shows what is commonly referred to as caustic gouging. Previ-

Abstract

Five examples of boiler tube failures caused by corrosion are discussed and illustrated with figures. Iron migration theory is briefly covered. Recent data on boiler corrosion are given to show that old theories may need modification to consider the corrosive factors presented by higher temperatures and greater pressures in boiler operations. The implication is made that corrosion can occur in boiler tubes despite the use of chemicals in boiler water. Two chemical methods of corrosion control are discussed: control of alkalinity and acid cleaning. The conclusion is made that under certain operating conditions periodic acid cleaning of boilers is essential if tube failures are to be avoided.   7.6.4

ously deposited sludge or corrosion products need not play a role in this instance if the tube is hot enough to cause high concentrations of caustic to develop in the film of boiler water next to the tube. Although this problem might be corrected by reducing the heat input in the affected region or by making mechanical changes that will improve rinsing, reduction of the caustic alkalinity of the boiler water may help.[8,9]

Figure 4 represents attack by boiler water at a field weld in a boiler tube. The deposit adjacent to the weld is iron oxide formed in place. As there were no foreign deposits in the area and the heat input at the weld was no greater than elsewhere, stresses created by the welding process are probably responsible for the localized attack. The type of damage shown here frequently has been reduced or eliminated by raising the boiler water alkalinity following acid cleaning of the boiler.[10] The higher alkalinity probably resulted in a toughening
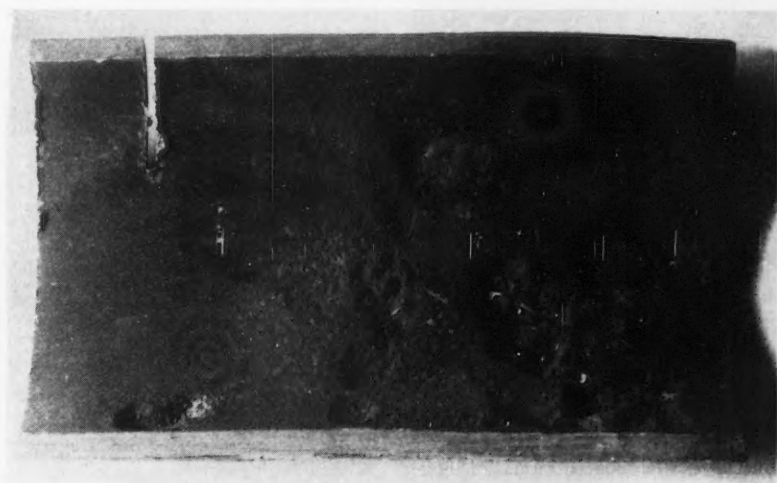
Figure 1—Pitting of boiler tube caused by oxygen in feedwater.

Figure 2—Boiler tube damaged by concentrated boiler water beneath iron oxide and copper deposits.
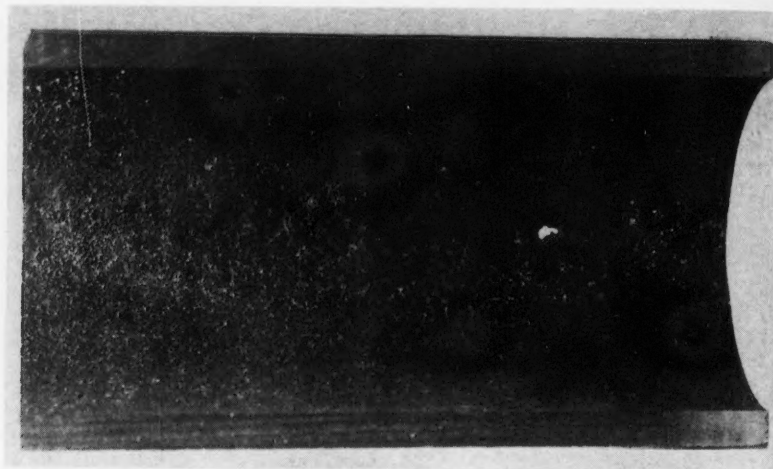
Figure 3—Boiler tube damaged by sodium hydroxide concentrated at surface by excessive heat input.

Figure 4—Corrosion at field weld in boiler tube probably aggravated by stresses in the metal.
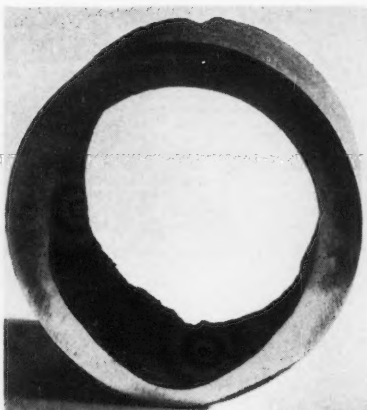
Figure 5—Dense magnetic iron oxide scab in boiler tube.

of the initially formed iron oxide which provided a tight barrier against the action of boiler water.

The type of corrosion illustrated in Figure 4 is not to be confused with attack by concentrated boiler water in crevices in the weld metal or beneath deposits precipitated by the orifice effect of backing rings. The latter types of attack are similar to that shown in Figure 2, except that some feature of the weld itself produces an environment in which boiler water solids can concentrate. Elimination of backing rings and the use of inert gases to exclude oxygen during the welding process help to relieve this problem by producing a smooth, welded surface that is not conducive to the concentration of boiler water

Recent laboratory investigations indicate that the chemical approach to boiler corrosion has some limitations. In Figure 5 is shown a section of generating tube in which a scab-like deposit of magnetic iron oxide obviously formed in place. Here is a kind of deposit that is not seen frequently, yet which may occur more often than visual examination would indicate simply because the scab-like deposit may have been cracked away from the metal by thermal shock. Many of the corroded areas of tubes may contain these heavy oxide deposits before a visual inspection is made, particularly if large pieces of magnetic iron oxide are found in the mud drum and headers. This specimen does not look like any of the previously discussed examples. The tube surface does not have the characteristic scattering of pits that are associated with oxygen. However, similar oxide deposits in other boilers[11] have been attributed to oxygen because appropriate remedies presumably prevented subsequent difficulty, but in that instance the boilers were also acid-cleaned. The importance of acid cleaning will be discussed later.

If formation of the hard, dense iron oxide shown in Figure 5 is attributed to caustic, it must be assumed that the caustic seeped through fractures in the oxide already formed and concentrated at the oxide-metal interface, constantly

uncovering new metal to the action of boiler water. If this argument were tenable, the newly formed oxide would be expected to grow beneath the old and thus fracture it. The extremely inelastic nature of magnetite[12] indicates the improbability of the oxide remaining intact under such circumstances.

Iron Migration Theory

The oxidation of iron by water need not be a simple reaction in which iron replaces hydrogen at the oxide-metal interface but may be the result of iron migrating through the oxide so that the oxide layer grows from the outside. That such a phenomenon occurs when iron is exposed to air at high temperature was first demonstrated by Pfeil[13] as early as 1929. However, recent work by Douglas and Zyzes[14] shows that this same process can happen when water is the corroding medium and when temperatures approximate those encountered in modern high-pressure boilers. The specimen in Figure 5 appears to be evidence that this process by which the iron turns itself inside-out actually does take place in an operating boiler. There is no void where the migrating iron came from because oxygen has migrated inward to form iron oxide beneath the existing oxide. As long as iron migrates outward faster than the oxygen migrates inward, there will be no fracturing of the previously formed oxide. Douglas and Zyzes find that the determining factor for the rate at which iron oxidizes above 465 F is the diffusion of iron outward.

Classical and Recent Corrosion Data

The fact that the formation of iron oxide in a boiler is a diffusion process controlled only by the rate at which iron diffuses through the oxide suggests that no concern need be given to the chemistry of boiler water. It seems, then, that corrosion of the boiler metal will proceed at a rate independent of the boiler water if the boiler is not operated at a pH that will dissolve the oxide. There is evidence to substantiate this statement. Bloom, Krulfeld, Frazer, and Vlannes[15] and Douglas and Zyzes[16] report data that show no significant difference in corrosion rates at pH 7 and pH 10.6 at 600 F after long periods.
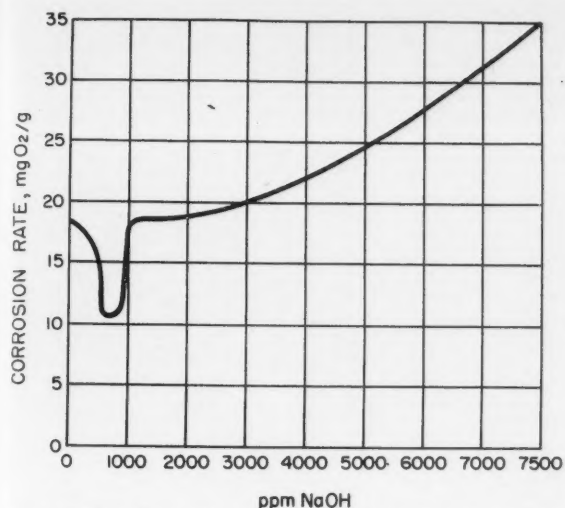
Figure 6—Effect of hydroxide concentration upon corrosion rates for 7½-hr. exposure at 590 F.[17]
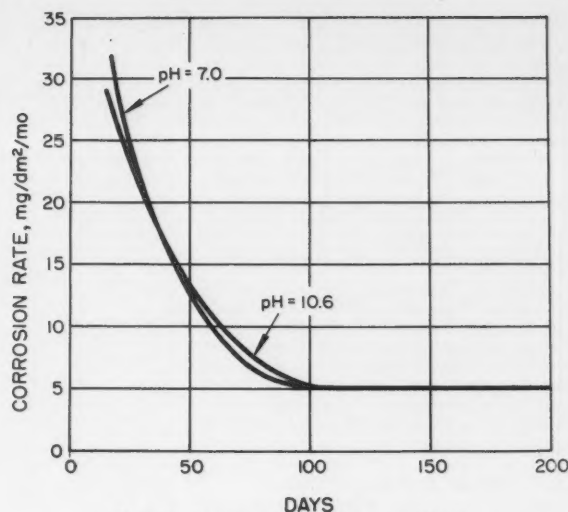
Figure 7—Corrosion rates in pure water at 600 F.[15]

This information may be a startling revelation to those familiar with the accepted practice of maintaining a residual of free caustic in boiler water. Valid experimental data can be given to support this tradition. Twenty-seven years ago Berl and van Taack[17] published the results of experimental work that indicated corrosion of carbon steel to be a function of pH and that a minimum corrosion rate is obtained at a pH slightly above 12. Wroughton, Seamon, and Brown,[18] studying the corrosive tendencies of high purity water in the primary circuit of pressurized water nuclear reactors, state that pH has a considerable effect upon corrosion rates, but they do not present data on corrosion rates or on the change of corrosion rates with time.

These seemingly contradictory data are presented graphically in Figures 6 and 7. The curve of Berl and van Taack[17] showing the effect of hydroxide concentration upon corrosion rates after 7½ hours is shown in Figure 6. The sodium hydroxide concentration that produces the least corrosion after 7½ hours is about 600 ppm. In otherwise pure water, this corresponds to a pH of 12.2. Curves fitted to the data of Bloom[15] showing corrosion rates in pure water and in water at pH 10.6 as a function of time are given in Figure 7. The two curves almost coincide, and after 100 days they become practically a horizontal straight line. Perhaps if Berl and Van Taack had increased the duration of their tests, the curve in Figure 6 would have been nearly a horizontal straight line.

The purpose of the present discussion is to try to determine the significance of laboratory corrosion data as they may be related to the actual generation of steam in a boiler. A boiler is a dynamic system in which there is a constant heat flux through the tube walls and in which water is circulating and possibly washing away some of the corrosion products. With one exception[18] the data of all the experimenters mentioned were obtained under thermal equilibrium and in small closed vessels with no flow of heat through the test surface and no flow of water past it. In the experiments of Wroughton[18] water with and without inhibitors was pumped continuously through an autoclave containing the test specimen, thereby removing some of the corrosion products from the system. This leads to the inference that the observations of investigators who conducted their tests in closed vessels and who found no effect of initial pH upon corrosion might be explained by the tendency of the pH of the originally pure water in the vessel to rise as corrosion progressed. However, Bloom[19] states that the capsules containing pure water continued to show a pH of 7 after exposure to 600 F for 24 hours or longer. This inconsistency certainly opens to question the applicability of bomb-type experiments to conditions existing in operating boilers. Testing that would permit not only the flow of water across the surface of the test specimen but also the flow of heat through the specimen would provide a notable contribution to research in the field of boiler corrosion.

Any increase in the pH of the corroding medium must be accounted for the presence of ferrous hydroxide, $Fe(OH)_2$. If the corrosion product is magnetite, Fe_3O_4, little or no increase would be expected. While the former compound is frequently found when corrosion occurs at room temperature, most investigators[20, 21] agree that Fe_3O_4 is the only significant product of corrosion at the temperatures for boiler operation. Although additional experimental work along these lines would be welcomed, evidence to date suggests that within certain limits the corrosion rate is nearly independent of the initial pH.

Test Data Related To Boiler Corrosion

If this hypothesis is accepted, what are its implications regarding the treatment of boiler water in high pressure systems where heat transfer rates are high and water is relatively pure? Perhaps corrosion cannot be prevented in spite of chemicals added. This is true to some extent because there will inevitably be migration of iron through the oxide film until one of three things happens: (a) the film becomes so thick that it resists the migration of iron ions and the rate of oxidation becomes negligible, (b) the thickening increases the temperature which speeds up the oxidation and failure results because of metal loss, or (c) the oxide forms a sufficient thermal barrier to cause the tube metal to fail from overheating. The latter is what happened to tubes adjacent to the specimen in Figure 5 that contained the massive scab of iron oxide.

Although there is good evidence that corrosion cannot be controlled directly by suitable adjustment of boiler water chemistry, the manner in which the corrosion products precipitate may be changed so that indirect control over corrosion is achieved. The ideal formation of iron oxide is to have a diffusion barrier sufficiently thick to slow down the rate of oxidation without providing a significant barrier to heat transfer. Also the formation should be dense rather than loosely consolidated because oxide in the latter condition would trap steam and water which would increase the insulating property of the film and perhaps provide an environment for the concentration of boiler water solids.

In explaining the observations of Bloom[15] that the corrosion rate becomes constant after long exposure, Douglas and Zyzes[16] state that iron oxide reaches a critical thickness beyond which it becomes porous and no longer offers a diffusion barrier. Thus the diffusion barrier remains at constant thickness and the corrosion rate remains constant. In the work performed by Bloom, the corrosion rate leveled off at 5 mg/dm²/mo, an extremely low rate, but in the laboratory experiments the temperature of the metal did not change as the oxide became thicker. If conditions inside a boiler permitted a similar phenomenon to occur, trouble would occur because the porous outer layer would continue to grow until it either sloughed off at a rate equal to its rate of formation or until it provided sufficient insulation for the tube metal to overheat. Both situations, of course, are undesirable. Loose iron oxide often accumulates in tubes inclined toward the horizontal and provides a trap for the concentration of boiler water with resulting caustic attack, or the accumulation simply insulates the tube from the boiler water.

Value of Controlling Alkalinity

There should be little doubt in the minds of those who have made numerous excursions through boilers treated with various amounts of caustic that

high levels of caustic alkalinity result in the formation of a thin, hard, dense layer of magnetic iron oxide over the steel. A residual of free sodium hydroxide throughout the boiler is considered beneficial because it produces a tough layer of reasonable thermal conductivity that remains in place. A striking example of the general improvement brought about by increasing boiler water alkalinity has already been discussed in connection with the tube damage illustrated in Figure 4 where attack had occurred at field welds.

However, the hard, dense layer of iron oxide observed in Figure 5 is itself a thermal barrier that is likely to grow thicker if the observations on free caustic are correct. Yet without a caustic residual, the porous or loosely consolidated iron oxide mentioned earlier will probably form and give the usual trouble associated with it.

Value of Acid Cleaning

Another chemical method to control boiler corrosion is acid cleaning. The necessity for acid cleaning implies that there are limitations on chemical treatment methods. It has been the purpose of this paper to point out these limitations. But acid cleaning should not be considered a last-resort measure for corrosion control.

Because the presence of dense iron oxide scabs in boiler tubes seems best explained by a diffusion process in which iron migrates from the tube metal through an iron oxide layer to the oxide-fluid interface, chemical methods of corrosion control must be re-evaluated in consideration of the fact that the only rate-controlling factors are temperature and oxide thickness. Although chemical treatment methods may alter the character of the oxide layer, they will not directly affect the rate of oxidation. Therefore, the best prescription for boilers which develop these dense, iron-oxide deposits is to acid clean before oxide formation has progressed too far and to use sodium hydroxide during operation to precipitate the oxide in its most desirable form.

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Any discussions of this article not published above will appear in the June, 1959 issue

Saudia Arabia Oil Well Drilling Corrosion Discussed

Corrosion of drill pipe in Saudi Arabia operations and color slides showing causes of the corrosion were given in a talk on Experiences in Oil Fields of Saudi Arabia by Maurri Banta of Battelle Memorial Institute. The technical program was presented at the Southwestern Ohio Section meeting, September 30 in Columbus.

Preceding the meeting, members made an inspection tour through the Columbus Army Depot. The depot handles more than 200,000 items, ranging in size from small springs to clam shell buckets. Of particular interest to corrosion engineers was the Care and Preservation Section which has the responsibility of preserving and shipping articles so that they are received intact and useful at any point in the world. Standardization of packaging is studied constantly for increased efficiency and lowered costs, the group was told.

A fellowship hour and dinner preceded the technical meeting.

SOME OF THE 127 who attended the September 24-25 Corrosion Field Tour sponsored by the San Joaquin Valley Section examine valves and header and line pipes taken from a natural gasoline plant. Twenty-one field exhibits were visited via bus throughout the Bakersfield, Calif., area. Types of corrosion seen on the tour were discussed in a general meeting.

Six Papers Are Added to Western Region Los Angeles Conference Program Nov. 17-21

Six papers have been added to the program for the Western Region Eighth Annual Corrosion Conference and Short Course. One paper listed on the tentative program in the October CORROSION will not be presented. Several changes have been made in the corrosion short course.

The conference will be held November 17-20 at the Statler Hotel, Los Angeles; the short course will be held in the field November 20-21.

The paper added to the Corrosion in Aircraft and Missiles Symposium is Chem-Mill Corrosion Problems by W. C. Rockwell, Chem-Mill Division, Turco Products.

Two papers are being added to the Marine Symposium: Coal Tar-Epoxy Resin Coatings by N. T. Shideler, Pittsburgh Coke and Chemical Co., and Corrosion Mitigation Studies at the Naval Civil Engineering Laboratory by R. Alumbaugh and C. V. Brouilette, U. S. Navy.

Papers added to the Petroleum Producing Symposium are Corrosion Measuring Techniques for Use in Water Flood Systems by C. Wright, Oil Well Research Co., and Corrosion Problems in Secondary Recovery.

An additional paper for the Chemical Process Industries Symposium is Stress Corrosion of Steam Generator Tubing in Nuclear Power Plants by D. E. White, Westinghouse Electric Corp.,

and E. G. Johnson, National Aluminate Corp.

In the Underground Structures Symposium, a paper entitled Development of a Pipe Coating Using Two Plastic Materials by B. E. Black and L. L. Whiteneck, Plicoflex, Inc., has been added. Problems of Water and Sewage in a Utility Company, a paper listed in the tentative program, will not be presented.

Additions and changes have also been made in the program for the Corrosion Short Course in the Field. The final program is as follows:

November 20, Morning

Chairman: J. Rasor, Tinker & Rasor Co.
Soil Resistivity Measurements
Pipe-to-Soil Potential Measurements
Chairman: P. C. Briley, National Lead Co.
Sandblasting of Pipe
Mechanical Cleaning of Pipe
Chemical Surface Preparation of Pipe

November 20, Afternoon

Chairman: W. J. Frith, Service Coating Corp.
Plastic Tank Lining
Vinyl Paint Pipe Application
Chairman: R. L. Hansen, Pipe Linings
Internal Cement Lining of Pipe
Tape Coating of Pipe

Coatings to Be Compared By San Francisco Section

Comparative Properties of Five Metal Protective Coatings is the subject for the San Francisco Bay Area Section meeting November 12 in San Francisco. Roy Landis, director of the Oakland laboratories of Sherwin-Williams, will be the speaker.

For the October 8 meeting, a talk on High Temperature Scaling in the Presence of Hydrogen Sulfide by E. W. Haycock, Shell Development Co., was scheduled. The subject included scaling both from the standpoint of theory based on extensive laboratory studies and from the practical standpoint. Environmental variables which influence high temperature sulfide scaling were a subject of discussion with a description of currently used preventive measures such as corrosion resistant materials.

Dr. Haycock holds a BSc and PhD from the University of Bristol, England. He conducted post doctoral research in the field of physical chemistry for two years at the University of California at Berkeley prior to joining Shell Development Co. in 1953. Most of his work has been in laboratory research dealing with such diverse subjects as adsorption on thin metal films, cathodic protection criteria and high temperature scaling in the presence of hydrogen sulfide.

Paint Thickness Talk Given

Dr. J. S. Long gave a talk on the Importance of Film Thickness in Painting Metal Surfaces at the October 1 meeting of the Southern New England Section held in Cheshire, Conn.

Six Papers Added—

November 21, Morning

Chairman: J. Rasor, Tinker & Rasor Co.
   Cathodic Protection Rectifiers
   Holiday Detectors

Chairman: P. C. Briley, National Lead Co.
   Prewelding and Postwelding Treatment of Pipe
   Phosphate Pipe Priming
   X-Ray Nondestructive Weld Inspection

November 21, Afternoon

Chairman: W. J. Frith, Service Coating Corp.
   Internal Plastic Lining of Pipe and Tanks
   Epoxy Resin Coatings

Chairman: R. L. Hansen, Pipe Linings
   Coating of Pipe Field Joints.

The region trustees will meet at a noon luncheon in the St. Louis room of the Statler Hotel, November 17. On the program for the banquet to be held in the Golden State Room, November 18, 8:00 p.m., is Adventures in Science, produced by the General Electric Co.

The welcoming address for the conference will be delivered November 17 by Norris Poulson, mayor of Los Angeles.

Corrosion Week Proclaimed

Proclamation of Corrosion Week in the City of Los Angeles during the NACE Western Region Conference there was made by Mayor Norris Poulson. The conference will be held November 17-19 at the Statler Hotel and will be followed by the Corrosion Short Course in the field, November 20-21.

The Mayor's proclamation calls attention to the millions of dollars lost by corrosion in the Los Angeles area. The work of NACE and corrosion engineers in attempts to reduce heavy corrosion costs in industry, utility services and the home is given in the proclamation.

Proposed Short Course Discussed at Birmingham

Election of officers, a discussion of progress on a corrosion short course, and plans for revising the section's by-laws were points of business at the Birmingham Section, September 5. Twenty-nine persons were present.

Officers for 1959 were elected by voice vote. They are Ralph Cunningham, Steele and Associates, Inc., chairman; John Paisley, Jr., American Telephone and Telegraph Co., vice chairman; Marion Fink, Tennessee Coal and Iron Division of U. S. Steel Corp., secretary-treasurer; and Lawrence Hicks, Southern Natural Gas Co., assistant secretary-treasurer.

Ralph Cunningham reported on progress of the proposed short course. Following a report by H. C. Van Nouhuys, Southeastern Pipe Line Co., based on experiences of a previous short course sponsored by the region, the following recommendations were made: An NACE member who travels throughout the area should be appointed to set up the course. A college should be asked to co-operate only if it were enthusiastic. A professor in the college metallurgical department should be contacted. Assistance should be obtained from NACE members living in the general area who have had past experience in setting up successful corrosion short courses.

Comparison with the by-laws for the Southeast Region indicated the need for revising the section's by-laws, it was stated. By vote of those present, William W. Garrett, section chairman, was directed to appoint a committee for revising the bylaws. Ralph Cunningham, Marion Fink and John Paisley were named to this committee.

Cathodic Protection Projects for Large Housing Developments is the title of the technical talk to be given at the last quarterly meeting of the section to be held December 5. C. J. Steele, Steele and Associates, Inc. will be the speaker.

Technical program for the September meeting was a talk on Deep Well Ground Beds—Construction and Maintenance, by Ralph Hurst, corrosion engineer, Mississippi Valley Gas Co. Mr. Hurst explained the reason for using deep ground beds details of how they are installed, and some of the results obtained.

Through experience with deep ground beds, design of installations have been changed. Three-inch by sixty-inch graphite anodes with individual No. 8 CP cables are now used. Drilling clay is pumped down through a ¾-inch pipe to provide a low resistance backfill in most cases. In the most recent bed installed, coke breeze was added to the sludge to further reduce resistance. However, difficulty was experienced in the pumping operation when the coke breeze clogged the pump. It is now planned to use screened coke breeze in a water suspension to overcome this.

Before a ground bed is installed, information on the soil formation and resistance is sought from bulletins, pamphlets or books published by the Mississippi State Geological Survey and other agencies and also from well drillers operating in the vicinity. Records are kept on all deep ground beds. A series of slides showing step-by-step procedure in installing the ground beds was shown.

In a question-answer session after his talk, Mr. Hurst said he recommends that his company use the deep well ground beds even though the cost is slightly higher for three reasons: (1) It is more economical in the long run. (2) More stable output and more output per volt are obtained because the installation is below the water line and in soil of lower resistance. (3) There is less interference on other companies' installations because of the relative location of the deep ground bed.

Attendance by those present at two region meetings, the national conference and corrosion show, and a joint section meeting was encouraged. The meetings were Southeast Region Conference, Richmond, Va., October 5-7; the South Central Region Conference, New Orleans, October 20-24; the NACE 15th Conference and 1959 Corrosion Show to be held in Chicago, March 16-20; and a joint meeting of the Jacksonville-Miami Sections, Miami, November 10-14.

All corrosion engineers interested in monthly meetings of the Birmingham Electrolysis Technical Committee were invited to attend the meetings which are held the first Wednesday of each month.

Kansas City Meetings Set

Plans for future meetings were discussed at the September 15 dinner held by the Kansas City Section. A representative from NACE headquarters is scheduled as speaker for November 10; Dr. F. S. Rowland of the University of Kansas will be the guest speaker at the December 8 meeting.

Ralph Miller of Spencer Chemical Company spoke on Corrosion in the Chemical Industry at the October 13 meeting.

Science Fair Committee Appointed by North Texas

Two members of the North Texas Section were appointed at the October 13 meeting to serve on the Science Fair Committee of the Council of Scientific Societies. Ed Muehlhause of Dallas and C. W. Gueue of Ft. Worth will represent the section on the Council Committee.

Science Fairs are conducted to stimulate interest among high school students in scientific studies. The Fairs also provide a science project which may require work throughout the school year and provide competition in scientific subjects on both local and national levels.

The North Texas Section has been asked by the Council of Scientific Societies to furnish technical assistance to the high schools and students wishing to participate in the Fairs, to furnish some financial help to defray expenses of sending winning students to contests, and to furnish qualified judges at the Fairs.

A new caliper to detect and measure corrosion in tubing was discussed at the October 13 meeting of the North Texas Section held in Dallas.

William G. Boyle, design engineer with Otis Engineering Corp., Dallas, explained the new caliper as a new type of recording instrument for measuring and classifying tubing according to internal surface defects.

Baltimore-Washington Officers to Be Installed

Officers elected for 1958-59 terms of the Baltimore-Washington Section will be installed at the Section's meeting on November 18.

The officers are: A. Clifton Burton, chairman, Research Laboratories, Armco Steel Corp., Baltimore; J. W. McAmis, vice-chairman, Washington Gas and Light Co., Washington, D. C.; and Herbert F. Lewis, secretary-treasurer, Southern Galvanizing Co., Baltimore.

Two speakers were featured at the September 16 meeting of the Baltimore-Washington Section. Preservation Coatings for Navy Ships and Activities of the Prevention of Deterioration Center of the National Academy of Sciences' Research Council were the topics.

The details involved in the selection of paints for use on U. S. Navy ships were outlined by Leon S. Birnbaum, head of the Preservation, Decking and Insulation Section, U. S. Navy Bureau of Ships, Washington, D. C. The problems of protecting Navy ship hulls was discussed, and information on paints being considered for use by the Navy was given.

The history and activities of the National Research Council of the National Academy of Sciences were presented in the talk by C. J. Wessel, director of the Council's Prevention of Deterioration Center. Mr. Wessel discussed his department's work as part of the Division of Chemistry and Chemical Technology. Supported by Armed Forces contracts, the Center provides information and advice on the prevention of deterioration of materials and equipment.

FRED H. MEYER, JR. SERVES AS SYMPOSIUM CHAIRMAN

Fred H. Meyer, Jr., served as chairman of the symposium on corrosion problems in the nuclear field at the North Central Region Technical Program last month in Cincinnati.

Mr. Meyer is head of the Corrosion Section, National Lead Company of Ohio, U. S. Atomic Energy Commission Fernald Project. His section works on problems involved in refining uranium from ore concentrates and application of corrosion resistant materials of construction. He has been active in NACE technical committee work and presently serves as vice chairman of T5A-5.

CORROSION incorrectly ran a photograph and biographical sketch of F. H. Meyer, Continental Oil Co., Ponca City, Okla., on pages 77 and 84 of the September issue.

Tubing Surveys Discussed

Interpretation of Tubing Caliper Surveys was the subject of a talk given by Ben D. Park, Sun Oil Company, Beaumont, Texas, at the September 25 meeting of the Teche Section.

Most of the 57 persons attending the meeting also attended the all-day meeting sponsored by the Teche Section on the inhibitor squeeze method.

The Teche Section Corrosion Control Short Course will be held in June.

Kansas City Section Plans Corrosion Short Course

A corrosion control short course may be scheduled after January 1 at Saint Teresa College in Kansas City if sufficient interest is shown. The course will be planned for eight weeks with one night class meeting each week. Cost will be $10 per student.

Persons interested should write Albert L. Kimmel, Midwest Research Institute, Industrial Chemical Section, 425 Volker Blvd., Kansas City 10, Missouri. A choice should be given of which week night would best suit the student.

SINGLE COPY PRICES OF CORROSION INCREASED

Effective at once the price of single copies of CORROSION to members of the National Association of Corrosion Engineers will be $1 each. The price of single copies to non-members of NACE will be $2 each.

For issues dated two or more years past (i.e. all issues dated 1956 or earlier) the price per copy is $2 to members and non-members alike.

NACE Abstract Service Subscriptions Available

New subscriptions and renewals are being accepted for the 1959 NACE Abstract Punch Card Service. Annual subscription rate is $175.

Approximately 2000 cards are sent each year to furnish subscribers with comprehensive abstracts of the corrosion field from 23 organizations. Each abstract card is marked for punching on a 2-row McBee punch card for topic, journal, author and date of publication. The cards are also pre-punched topically for up to five cross-indices.

Additional information on the abstract card service can be obtained by writing to Central Offices, National Association of Corrosion Engineers.

Some back issues of the card service are available for sale and can be obtained from the Central Office.

The annual subscription rate was $100 per year, but this rate proved inadequate to support the service on a cost basis. The NACE board of directors instructed the Executive Secretary last March to increase the rate to $175.

Cook Memorial Award Made at Detroit Meeting

The annual L. D. Cook memorial meeting of the Detroit Section was held September 18. McKay E. Padmos was presented the L. D. Cook Memorial Award for outstanding research in the field of corrosion engineering at Wayne State University, where he has done graduate work in the Chemical and Metallurgical Engineering Department.

Dr. L. W. Gleekman of Wyandotte Chemicals Corp., spoke on the scope and activities of his company's materials engineering group. Examples of corrosion problems encountered with coatings, plastics and metals were discussed. A trip through the Materials Engineering Laboratory was made.

North Texas Section

Nominations for officers to head the North Texas Section during 1959 have been announced to section members by the nominating committee. Nominees are Richard B. Bender, Plastic Engineering and Sales Corp., Fort Worth, chairman; Donald F. Taylor, Jr., Otis Engineering Corp., Dallas, vice chairman; Jerry R. McIntyre, Atlantic Refining Co., Dallas, secretary-treasurer; and Glyn Beesley, Dallas Power and Light Co., Dallas, trustee. Section trustees are elected every other year.

Nominees were to be present at the October section meeting. Provision was made for the candidates to be nominated from the floor at the meeting.

Shreveport Section Meets

Role of the Remote Electrode in Cathodic Protection Work was the subject of a technical talk scheduled for the Shreveport Section meeting, October 7. Maurice Riordan of Rio Engineering, Houston, was selected as the speaker for the meeting. A social hour followed by a dinner was planned.

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CORROSION's index appears in December.

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OUR SCIENTIFIC EDUCATIONAL PLIGHT—Fact or Fancy, a talk by Dr. Mayne Longnecker of Southern Methodist University, was given at the North Texas Section meeting held September 8 in Dallas. Shown from left to right are E. J. Simmons, Sun Oil Co., section vice chairman; Dr. Longnecker; Glyn Beesley, Dallas Power and Light Co., chairman; and Donald F. Taylor, Jr., Otis Pressure Control, Inc., secretary-treasurer.

Second Annual Shrimp Boil Held by Teche Section

The second annual Shrimp Boil and Barbecue was held October 10 in Lafayette, La., by the Teche Section.

A talk on Interpretation of Tubing Caliper Surveys by Ben D. Park, Sun Oil Co., Beaumont, was scheduled as the technical program for the September meeting held at the Petroleum Club.

Air Pollution Conference To Be Held Nov. 18-20

The National Conference on Air Pollution is being held at the Sheraton Park Hotel in Washington, D.C., November 18-20, according to Mr. Head of the U.S. Public Health Service. This interdisciplinary meeting has been called by Dr. Leroy E. Burney, Surgeon General, Public Health Service, U. S. Department of Health, Education and Welfare.

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The Canadian Region meeting will be held January 12-14 in Montreal, Quebec.

SECTION CALENDAR

Nov.

4   Shreveport Section, Caddo Hotel. Fellowship hour, 6 pm. Deep Ground Beds for Protection of Transmission Lines.

10   Kansas City Section. Corrosion in the Chemical Industry, Ralph Miller, Spencer Chemical Co.

12   Metropolitan New York Section. In Newark. Marine Corrosion Panel— F. J. McGinity, leader.

18   Chicago Section. Metallic Coatings, by David W. Levinson, Armour Research Foundation. Joint meeting with The Electrochemical Society.

20   Vancouver Section. In B. C. Electric Bldg. Auditorium. Corrosion in Aircraft, by R. Tate, Canadian Pacific Airlines.

20   Kanawha Valley Section.

25   Panhandle Section.

Dec.

10   Metropolitan New York Section. In New York City. Corrosion of Iron and Steel, by C. P. Larrabee, United States Steel Corp., Monroeville, Pa.

12   Birmingham Section. Cathodic Protection Project for Large Housing Developments, by Jay Steele, Steele & Associates, Inc.

12   San Diego Section.

18   Vancouver Section.

Electrochemical Processes Discussed at Longview

The electrochemical processes of corrosion were explained by Donald Emerick of Centenary College, Shreveport, at the September 23 meeting of the East Texas Section held in Longview. He pointed out that the corrosive potential was determined by the primary chemical reactions while the secondary chemical reactions controlled the corrosion rate.

A nominating committee composed of E. L. Chapin, J. H. Graves and D. S. Simon was appointed to present nominees for 1959 officers to be elected at the November meeting.

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Deadline for news stories in CORROSION is the tenth of the month.

NEW COMMITTEE WORK PROPOSED ON ALUMINUM

Formation of a unit committee under T-2 "Pipe Line Corrosion" has been suggested to explore the possibility of cathodic protection of buried aluminum pipe lines. This problem has been relatively unexplored.

Persons desiring to participate in this committee should write to Dr. H. P. Godard, Aluminium Laboratories, Ltd., P. O. Box 84, Kingston, Ontario, Canada.

An organizational committee meeting will be held in Chicago next March if sufficient interest is shown.

'59 Houston Short Course Scheduled for Jan. 22-23

The annual Houston Section Short Course will be held January 22-23 in Oberholtzer Hall at the University of Houston. The course will be devoted primarily to the fundamentals of corrosion. All interested persons are invited. Lecturers and subjects will be announced later.

Peddlers' Meeting Held

The annual "peddlers" meeting of the San Diego Section was held September 24 in La Mesa, Cal. Three salesmen members gave brief descriptions of their products. Insulating couplings, paint films, plastics, and tapes were discussed.

NATIONAL and REGIONAL MEETINGS and SHORT COURSES

1959

Jan. 12-14—Canadian Region. Sheraton Mount Royal Hotel, Montreal, Quebec.

Feb. 11-13—Canadian Region. Calgary, Alberta.

March 16-20—15th Annual Conference and 1959 Corrosion Show. Sherman Hotel, Chicago.

Sept. 29-30, Oct. 1—Western Region Conference. Bakersfield Inn, Bakersfield, Cal.

Oct. 5-7—Northeast Region. Lord Baltimore Hotel, Baltimore, Md.

Oct. 12-15—South Central Region Meeting, Denver, Col.

Oct. 20-22—North Central Region, Cleveland.

1960

March—16th Annual Conference and 1960 Corrosion Show. Dallas, Texas, Memorial Auditorium.

Oct. 11-14—Northeast Region Meeting. Huntington, W. Va.

Oct. 25-28—South Central Region Conference, Mayo Hotel, Tulsa.

1961

March—17th Annual Conference and 1961 Corrosion Show. Buffalo, N. Y., Hotel Statler.

Oct. 24-27—South Central Region Conference, Houston, Shamrock Hotel.

1962

March—18th Annual Conference and 1962 Corrosion Show. Kansas City, Municipal Auditorium.

October 16-19—South Central Region Conference, San Antonio, Texas.

SHORT COURSES

1958

Nov. 10-14. Corrosion Short Course. Key Biscayne Hotel, Miami. Miami and Jacksonville Sections, NACE.

Nov. 20-21—Los Angeles Section. Corrosion of Underground Structures.

1959

January 22-23. Houston Section. Short Course on Fundamentals of Corrosion Control. University of Houston, Oberholtzer Hall.

March 31-April 12. Corrosion Control Short Course. University of Oklahoma-Central Oklahoma Section. North Campus, University of Oklahoma, Norman.

June—Teche Section. Corrosion Control Short Course.

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NACE regional and sectional secretaries who do not have a supply already may get copies of the form "News Report for Corrosion" from Central Office on request. The form helps in providing a complete news story concerning meetings. The news deadline for CORROSION is the tenth of the month preceding month of issue.

A "PRUFCOAT SERVICE" PROFILE
(one of a series)

From the Desk of Your EXECUTIVE SECRETARY
T. J. Hull, Executive Secretary

• Most Abstract Card Service Subscribers Are Satisfied

A survey of the subscribers to the NACE Abstract Punch Card Service made in July has shown that most subscribers are satisfied with the service as it is now being conducted. The subscribers were asked to give their views concerning several alternative methods of producing and issuing the abstract information.

A test search is now being made in the abstract cards on file at Central Office to determine the cost of a search service, its effectiveness, and on what basis it can be offered by the association as an extension of its abstracting activities.

• New Type Style for Corrosion's Technical Section Approved

Effective with the January, 1959 issue of CORROSION the size and style of type to be used to set the section will be changed. The type will be about 15 percent larger than the type used during 1958. The aim is to improve legibility and not increase unduly the space occupied by the section.

• Readership Survey Results

In July, a survey of CORROSION readers was made to determine the relative popularity of the features published in CORROSION; to discover areas of interest and indifference; to get an estimate of total readership; to learn the extent of times copies are used; and to collect general comments. A summary of the results is:

1. There is a pronounced demand for additional technical information in the areas of case history data and discussions of fundamentals and mechanisms. Demand for additional data on most topics was oriented to the industrial interests of the respondents. Several requests were made for publication on a repetitive basis of fundamental information on corrosion and corrosion mitigation methods.

2. Order of interest in subdivisions of CORROSION is about as anticipated except that there is less interest in Technical Committee Activities and NACE News than expected. New Products is third in order of interest.

3. Average readership per copy is 3.8. More than half keep Corrosion indefinitely for reference.

4. 41 percent do not use the annual alphabetical subject index.

5. Of 46 comments that could be classified, 37 (80 percent) were complimentary, the remainder critical.

6. Miscellaneous comments showed no definite pattern.

7. There was no marked difference in the pattern of interest distribution among the industrial areas tabulated.

• Membership Dues Billed Early

This year, NACE members will be billed for their dues in October. In past years, dues invoices have not been mailed until December. There is a lapse of three to four months from the time the invoices are mailed until the time we can with any accuracy determine how many members do not intend to pay their dues. The by-laws require that all association publications be sent to members for three months after the time their dues become in arrears. Each year, around 1000 copies of CORROSION are sent to those who do not intend to retain their memberships. By billing members three months before January 1, we hope to eliminate this waste.

• NACE Participates in Physical Metallurgy Conference

NACE is one of four associations cooperating in sponsoring a conference of "Physical Metallurgy of Stress Corrosion Fractures" at Mellon Institute at Pittsburgh, on April 2-3, 1959. Other societies involved are: The Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers; Electrochemical Society, American Society for Testing Materials. The program is designed to provide a broad basis for presentation and discussion of recent fundamental advances in stress corrosion cracking.

W. B. Brooks, Dow Chemical Company, Freeport, Texas has been appointed by President Whiteneck to act as the official NACE representative on the conference program committee. Attendance will be limited to 400.

Executive Secretary—

• 1959 Conference and Corrosion Show

Plans and arrangements for the 15th Annual NACE Conference and 1959 Corrosion Show are virtually complete.

So many technical papers have been offered that several symposia have been expanded into full day sessions. Notable among these is the Pulp and Paper Industry Symposium. Plans are being made to give this symposium wide publicity by the Technical Association of the Pulp and Paper Industry.

• 1960 Conference Plans Progress

J. C. Spalding, Jr., Sun Oil Company, Dallas has been appointed General Conference Chairman for the 1960 Conference. Gordon Meek, Metal Goods Corporation, Dallas has been selected as Mr. Spalding's co-chairman. Mr. Meek also will serve as chairman of the local arrangements committee.

The exhibition in 1960 will be held in the Dallas Memorial Auditorium. The Adolphus and Baker hotels have been selected as joint headquarters hotels for the conference. These hotels are located across the street from each other and two blocks from the auditorium. The Adolphus and Baker hotels have guaranteed enough sleeping rooms and suites to house our conference. Hotel rooms will be available in other hotels should registrants wish to be housed in hotels other than the Adolphus and Baker.

• 1964 Conference

Los Angeles and St. Louis have made bids for the 1964 Conference. Preliminary discussions on the location for the 1964 Conference will be held at the executive committee meeting scheduled October 21 in New Orleans.

• Educational Films' Progress

The NACE Film Advisory Committee has completed the scripts for the films on Fundamentals and Pipe Line Coatings. A copy of the final scripts will be submitted to the executive committee for approval at the NACE policy level.

Paper Available on Water Purity for Nuclear Plants

A paper on the water requirements for nuclear plants is available from Graver Water Conditioning Co., 216 West 14th Street, New York 11. It discusses the reasons for the extreme water purity requirements in nuclear cycles including considerations of efficient heat transfer, radioactivity, corrosion, materials of cycle construction and fuel element fracture.

Plastic Engineers Society To Meet in Los Angeles

Meeting of the Southern California Section of the Society of Plastics Engineers is being held November 13 in Los Angeles. Abstracts of papers to be presented can be obtained from Lloyd Dickson, Publicity Chairman, Houghton Laboratories, 5920 Smiley Drive, Culver City, Cal.

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Deadline for news stories in CORROSION is the tenth of the month.

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GENERAL NEWS

SOME OF THE REGISTRANTS at the September 13 practical coating school conducted by the Coating Society of the Houston Area are shown here examining the specimen of steel plate sandblasted during one of the demonstrations. Demonstrations of other cleaning techniques and tools, paint pressure and hot spray equipment and other coatings information were made available for the registrants. A second session of the school was held September 20.

PVC Materials Used To Make Time Capsule

A time capsule made of unplasticized polyvinyl chloride will be sealed in the cornerstone of a new Kentucky amphitheater near the site where Stephen Foster was inspired to write "My Old Kentucky Home." Believed to be the first time capsule made of this industrial plastic material, the cylinder will contain tributes to the composer by President Eisenhower and other national persons.

Made up of parts regularly manufactured for piping used in handling corrosive liquids and gases, the capsule was made by Tube Turns Plastics, Inc., Louisville, Kentucky.

French Plastic Production Increased 25 Percent

Production of plastics in France has increased 25 percent in the last year and is expected to expand 250 percent above 1956 totals. A new plant on the Ivory Coast of Africa in the French Overseas Union is being constructed to utilize vinyl, polyethylene, polystyrene, polyester and cellulose acetate materials in the manufacture of plastics.

UN Publishes Proceedings

Proceedings of the second international conference on the peaceful use of atomic energy will be published by the United Nations. Available in a pro-

posed set of 34 volumes or by individual volumes, the proceedings will cover such subjects as production and use of isotopes in research, use of isotopes in industry, chemical effects of radiation and basic studies in metallurgy and ceramics.

Inco Teaching Fellowship Renewed at Oklahoma U

A $4000 teaching fellowship at the metallurgical engineering school of University of Oklahoma has been renewed by International Nickel Corp. This fellowship provides $3000 for graduate student William Lorkavic and $1000 to the school for equipment and supplies to support the student's work.

Purpose of International Nickel's fellowship program is to encourage students to continue graduate study for preparation as teachers of science, particularly metallurgy.

Porcelain Forum Planned

With the forum theme "Modern Practices in Porcelain Enameling," the Porcelain Enamel Institute scheduled the following papers for presentation at its November 5-7 Shop Practice Forum at the University of Illinois: metal preparation pickling procedures—adjustments for various soils, standardization of coating thickness gauges, revised commercial porcelain enameled tanks for domestic hot water service, use of IBM 704 computer to reduce weathering test data and adhesives for laminating panels.

BOOK NEWS

Development of an Improved Corrosion Inhibitor for Water-Alcohol Solutions. By D. B. Conklin, B. G. Peacock and J. E. Cole. 82 pages. July, 1956. Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. Per copy, $2.25.

An effective corrosion inhibitor was developed for use with alcohol-water injection fluid for aircraft engines. It inhibits corrosion of steel, stainless steel, and aluminum alloys; it is soluble in methanol, ethanol, water or mixtures of the liquids and lowers surface tension of the mixtures.

Preparation of Protective Coatings by Electrophoretic Methods. By A. C. Werner and R. J. Abelson. 26 pages. February, 1958. Office of Technical Service, U. S. Department of Commerce, Washington 25, D. C. Per copy, 75 cents.

A process for depositing alloys to serve as intergranular diffusion barriers between the molybdenum and the nickel-chromium layer is described. After electrophoretic application, multi-layer coatings of 80 nickel-20 chromium and nickel-bonded columbium and titanium carbide provided oxidation and erosion resistance. Improvements were made in coating techniques to permit coating in one operation rather than two, and coatings were prepared on the 0.5 percent titanium alloy and on wedge-shaped pieces with few failures.

Thin Metals Films as Corrosion Indicators. By R. B. Belser and F. E. Hankinson. 98 pages. May, 1958. Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. Per copy, $2.25.

This study was aimed at filling the need for a sensitive, easily inspected, economical corrosion indicator which would integrate, with respect to time, the total exposure of packaged material to corrosive conditions. An examination of the corrosion properties and rates of iron and manganese films and of the bimetal pairs of iron-copper and iron-gold is described.

Compatibility of VCI With Rubber. By R. L. LeMar. 21 pages. September, 1957. Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. Per copy, 75 cents.

As a result of this study, VCI (volatile corrosion inhibitor) papers are recommended for the preservation of ferrous metal items where rubber fabrications are an integral part of the preserved item. The papers were found to have less effect on rubbers than most oils. For the tests, commercial VCI papers were wrapped around samples of rubber formulations. The combinations were exposed to dry and moist aging at 130 F. Effects of the VCI were determined by analysis of volume change, elongation, and tensile properties of the ruber.

ASRE and ASHAE Vote On Plans to Merge

The American Society of Refrigerating Engineers will hold its semi-annual meeting in New Orleans, December 1-3. The technical program will consist of 12 papers dealing with the refrigeration and air conditioning fields plus three conferences and six forums.

Members of ASRE will vote at this meeting to decide on a proposed merger with American Society of Heating and Air Conditioning Engineers. Members of ASHAE will be voting December 1 in Chicago on the merger.

Building Research Meeting

The Building Research Institute conference to be held December 3-4 in Washington, D. C., will feature information on new paints and protective coatings, methods of application, surface preparation, deterioration of paints and special finishes for problem situations.

Nuclear Congress Planned

Dates for the 1959 Nuclear Congress sponsored by the Engineers Joint Council have been set for April 5-10, 1959. Meetings will be held in Cleveland.

PERIODICALS

Current Contents of Chemical Publications. $5\frac{1}{2}$ x $8\frac{1}{2}$ inches. Weekly. Eugene Garfield Associates, 1523 Spring Garden Street, Philadelphia 30, Pa. Subscription: Domestic, per year $100; Europe and South America, $150; Asia, Africa and Australia, $175.

Tables of contents of more than 350 publications, including translations of Russian and Japanese titles, will be given in this new weekly magazine to begin publication in January. Research in pure and applied chemistry, engineering, operations research and petroleum will be covered. Photographic reproductions of advance or current tables of contents from the magazines will be used.

Pakistan Journal of Scientific and Industrial Research. Vol. 1, No. 1, January, 1958. Published quarterly by the Publications Branch, Pakistan Council of Scientific and Industrial Research, 3/4/D/IV, Nazimabad, Karachi, Pakistan. Subscription orders should be sent to the Associate Editor. Annual subscription: Rs. 15/- post free. Single copies: 4/- post free.

The first issue of this scientific journal represents the efforts of the Council of Scientific and Industrial Research to disseminate both scientific and technological information to encourage original research in both pure and applied fields.

The journal is being published as a quarterly, but plans are being made to develop the publication into a monthly as soon as possible.

The contents of the first issue range in subjects from nuclear physics, electronics and geology to biology and pharmacy. The entire journal is printed in English.

BOOK NEWS

(Continued From Page 81)

Your Most Important Raw Material. By Everett P. Partridge. 27 pages. 6 x 9 inches, paper. May, 1958 American Society for Testing Materials. 1916 Race Street, Philadelphia 3, Pa. Per copy, $1.25.

Presented as a lecture before the sixtieth annual meeting of ASTM, this book discusses the importance of water to industry. Statistics show the geographic distribution of water sources and the amounts of water withdrawn in various regions of the U. S.

One of the significant sections of the book deals with the industrial use of water as a coolant. Showing that probably 85 percent of the water withdrawn by industry is used for cooling, the book discusses the topics of withdrawal versus consumption in cooling and once-through cooling.

Other sections deal with water as a means of converting energy, transportation and by-products.

Research On Power From Fusion and Other Major Activities in the Atomic Energy Programs; January-June 1958. Published by the U. S. Atomic Energy Commission. 410 pages, $5\frac{3}{4}$ x 9 inches, paper. July, 1958. Superintendent of Documents, United States Government Printing Office, Washington 25, D. C. Per copy, $1.25.

This book is divided into two sections: major activities in the atomic energy programs and progress toward producing power from controlled fusion.

A summary is also given of the AEC activities in reactor development, controlled thermonuclear research, industrial development, education and training, production of materials and peaceful uses of nuclear explosives.

Iron and Steel Dictionary: German-English/English-German. Edited by Verein Deutscher Eisenhuttenleute in collaboration with The Iron and Steel Institute. 272 pages. 4 x 6 inches, imitation leather. 1958. Verlag Stahleisen M.B.H., Breite Strasse 27, Postschliessfach 2590, Dusseldorf, West Germany. Per copy, DM 12, 50.

A new English-German technical dictionary for use in the iron and steel industries has been published. It has over 7000 technical terms and also includes important business terms and many conversion tables to facilitate rapid conversion of British and American units into German and vice versa.

List of 600 UN Papers Issued on Technical Topics

A list of more than 600 U. S. technical papers given at the Second International United Nations Conference on Peaceful Uses of Atomic Energy is available from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., for 25 cents per copy.

The following research areas are covered: chemistry and chemical engineering; fabrication of fuel elements; geology, exploration and mining; metallurgy and materials; nuclear physics; ore processing; power reactors; radiation effects of material; reactor physics; and waste disposal.

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NEW PRODUCTS

Equipment
Services

Materials
Literature

Adhesives

A **Rubber-like Adhesive** that will bond to almost any surface has been announced by B. F. Goodrich Industrial Products Co., Akron, Ohio. Chemical hooks attached to each molecule of the material compel the adhesive to cling to and join surfaces to form a lasting bond. Known as A-916-B, it is available now as a laminating adhesive to bond new synthetic films to all kinds of metals as well as to paper, wood, glass, plaster and other materials without heat or special surface treatment.

Aluminum

Aluminum-clad Homes developed by National Homes Corp., Lafayette, Ind., and Aluminum Company of America are the first major usage of aluminum in production homes. Available in sizes from 925 sq ft to 1700 sq ft, the dwellings are completely faced in aluminum and use a new aluminum roofing system designed and developed by Alcoa. Named the Viking Line, these production homes cost the same as conventional residences of wood, stone or brick.

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Unitrace Pipe in sizes up to 6 inches is being produced now by Aluminum Company of America in Philadelphia. Larger sizes of this extruded pipe with integral steam passage are required to transport economically large volumes of bulk material such as urea, fuel oil and asphalt.

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The Fairchild Aluminum Bridge, which employs proven aircraft design principles and is more economical than conventional spans of other materials, has passed extensive tests at Lehigh University. Designed by Fairchild Engine and Airplane Corp., 500 Walker Bldg., Washington 5, D. C., the bridge is competitive in initial cost with conventional structures. Long-range savings are also realized because the aluminum bridge will never require paintings.

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Six Aluminum Coal Trailers have been built by General American Transportation Co., Chicago, for Aluminum Company of America. Designed to haul almost 60 tons of coal, the trailers were made of aluminum to reduce gross weight over 10,000 pounds in comparison with similar trailers made of steel and to reduce maintenance costs caused by corrosion.

Cleaning

A **Heavy-duty Cleaner and Degreaser,** Harco Safety Spray can be used for degreasing machinery, motors, diesel equipment, plant fixtures, tile, floors, range hoods, and exhaust fans. The spray contains inhibitors to prevent rust and corrosion of all metal surfaces. A bulletin giving uses and dilution suggestions is available from Harco Chemical Co., Cranford, N. J.

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Enthol 59, a non-flammable phospheric acid-type cleaner and deruster is usable on most metals. Blended of phosphoric acid with emulsifiers, solvents and penetrants, the cleaner removes rust, metal oxides, oil and grease from metals in one operation. A light phosphate film is left by the cleaner on steel and zinc as a base for painting or other organic finishing. Enthon 59 is manufactured by Enthone, Inc., 442 Elm Street, New Haven, Conn.

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Steel Needles in the Von Arx Air Gun will clean and de-scale uneven surfaces. Reciprocating rapidly, the needles conform to surface contours and clean crevices, holes and corners. The gun operates on normal air pressure, not more than 90 psi. It is available from Marindus Company, 52 Wall Street, New York 5.

Coatings—Organic

Turcoat 3557, a new phosphate material for use as an anti-friction break-in coating, has been developed by Turco Products, Inc., 6135 South Central Avenue, Los Angeles 1. Normally used as a break-in coating for moving parts, Turcoat can also be used for rust-proofing small parts to be oiled in mass production. It also serves as a foundation for paint, and is suitable for coating pistons, gears, crankshafts, ordnance parts, clips, bolts, nuts, fasteners, tools, compressor shafts, and lubrication boxes.

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Rustikote, a new coating for protecting and preserving rusted and pitted iron or steel surfaces which cannot be properly prepared for protective painting, has been developed by Tropical Paint Co., Cleveland 2. After loose rust is removed, Rustikote bonds firmly to surfaces and pitted areas, setting up a hard, dense, protective film. Tropical chemists say that Rustikote is an effective finish without additional finish coats.

Coatings—Metallic

Pyro-Plates, a nickel composition of paint-like consistency, is brushed, dipped or sprayed on any ferrous metal or copper to provide resistance to corrosion, oxidation and abrasion. Tests show the plating to have corrosion resistant properties of pure nickel plus a self-quenching action inhibiting continued corrosion if the plate is cut or scratched through to base metal. The metallurgical bond fusing the plate into the base metal surface prohibits cracking, chipping, peeling or lifting of the plate as found in mechanically bonded chemical and electrolytic plates. An illustrated brochure is available from TODCO, P. O. Box 229, Whittier, Cal.

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World's Largest Galvanizing Kettle has been built by Lukens Steel Company for Valcon Galvanizing, Inc., Natrona, Pa. Measuring 40 ft by 51 inches by 6 ft 10 inches, the kettle will handle large steel trusses, pipe, plates, oil derricks, tanks, grating, chains, bars, expanded metal and other steel structurals. With 40 feet of head room, large steel members can be lifted straight up from the kettle to be drained length-wise for smoother zinc finishing.

Containers

A **Terne Plate** five-gallon safety can in a new oval shape to save space is being manufactured by the Protectoseal Company, 1920 So. Western Avenue, Chicago 8. Greater resistance to corrosion on inside and outside surfaces is obtained by the use of terne plate.

Fasteners

Nuts, Bolts, Washers and Lag Screws for use under severe corrosion conditions at chemical plants are being made by Haynes Stellite Company, Kokomo, Indiana. Samples of the fasteners made of Hastelloy Alloy C were corrosion tested in wet chlorine and showed a corrosion rate of only 0.0039 ipy after a 15-hour test.

Filters

Porous Carbon Filter Tubes in a variety of styles for any type of tube filtering equipment can be supplied with any desired internal or external machining by National Carbon Company, 30 E. 42nd Street, New York 17, N. Y. Typical configurations of filter tubes include plain open-end, blind end, counterbored and blind-end with collar flange.

Fittings

A **Brass Flareless Tube Fitting** that makes a butt joint has been announced by Imperial Brass Mfg. Co., 6300 W. Howard Street, Chicago 48. There is no need to spring the tubing to make connections since the butt joint eliminates tube entry into the throat of the fitting. Closer tube bends are possible to give greater tolerance in tube length and placement, thus making installation speedier.

Instruments

A **Humidity Indicator** to measure the percentage of relative humidity in air is available from Abbeon Supply Co.,

NEW PRODUCTS

(Continued From Page 85)

179-45B Jamaica Avenue, Jamaica 32, N. Y. It has an upper temperature range limit of 230 F.

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Pneumatic Temperature Controls with recording or indicating devices is available from Pratlow Corp., New Hartford, N. Y. They actuate an air-operated throttling valve which controls the flow of steam, water or gas or operates other air-operated devices. Using no electricity, they are explosion proof.

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Pressure Blasting Analyzer (PBA), an instrument designed to help workmen locate trouble spots in sandblasting equipment, will accurately measure the air pressures in pounds per cubic foot per minute and also measure the inside orifice of the sandblasting nozzle in use, showing the measurement in inches and the air volume required in cubic feet per minute. The PBA helps to avoid such costly operation errors as over-rated compressors, improperly designed equipment and accessories and ruptured liners in air or sandblast hose. It is available from E. W. Oakes Co., P. O. Box 9102, Houston 11.

Ion Exchange

A Saline Water Conversion Plant is being used by a New York restaurant to produce fresh, potable water for drinking, cooking and all restaurant operations plus air conditioning and boiler makeup. The desalter will remove about 200 lb of undesirable salts each day from 12,000 gallons of brackish well water. This unit is expected to produce water at an operating cost of about 50 cents per thousand gallons, according to the manufacturer, Ionics, Inc., 152 Sixth Street, Cambridge 42, Mass.

Laboratories

A New Research Center that will probe a wide range of related scientific subjects has been opened by Electric Storage Battery Company in Yardley, Pa. This center will be used for research in such diverse areas as plastics, metallurgy and special membranes for use in large scale desalting of water.

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A New Research Laboratory for Tube-Kote, Inc., *2727 Holmes Road, Houston,* for the coating evaluation activities of the firm has been dedicated. In addition to research on oil field tubular linings, a company specialty for years, the expanded facilities will allow company engineers to make recommendations concerning protective coatings and specialized coatings where needed. The firm also handles the coating of storage tanks, tank cars, trailer tanks and other fabricated tanks and piping.

Metals—Ferrous

A One-piece Wellhead made of stainless steel for offshore drilling applications is being produced by Cosasco Division of Perfect Circle Corp., 11655 McBean Drive, El Monte, Cal. It is designed for installation on the ocean floor or for use in tideland locations where splash-area protection is necessary.

Metals—Non-ferrous

Zinc as a Thin Foil is being produced by a new continuous process developed by American Smelting and Refining Company at its Central Research Laboratory at South Plainfield, N. J. Zinc is deposited electrolytically from a zinc sulfate bath onto a revolving drum and then stripped off in a continuous sheet of uniform thickness. Sheets in 0.005 to 0.001 inch in thickness and 26 inches in width are being produced. As a moisture barrier in insulating compositions the zinc foil has the advantage of adhering to bituminous materials better than other metallic foils.

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Beryllium Oxide Shapes designed for new applications in the nuclear, aircraft and missile and electronics industries are being produced now through hot-press and machine operations by Beryllium Corp., Reading, Pa. Beryllium oxide's characteristics—low neutron capture cross-section, high thermal conductivity, high electrical resistivity and dielectric strength—make these machined shapes useful in the field of advanced nuclear reactors where temperatures preclude the use of present-day reactor materials.

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Beryllium-Copper Tubing in small diameters is described in Data Memorandum No. 7 published by Superior Tube Company, 1714 Germantown Avenue, Norristown, Pa. The data include mechanical and physical properties, applications, corrosion resistance, production limits, heat treatment, fabrication and standard size tolerances.

Pipe Line Equipment

Paper Molds for coating joints and cutbacks are distributed by Dearborn Chemical Company, 375 Merchandise Mart, Chicago 54. The molds are used to coat joints with the same material and manner of application as mill-coated pipe for corrosion protection. They are available for standard pipe diameters up to six inches.

Plants

Chem-Care Products, Inc., is the new name for Building Maintenance Supply of Glendale, Cal. A new building at 710 West Wilson Avenue will expand the facilities of this industrial chemical company which supplies hot and cold tank cleaners, paint strippers, emulsion and solvent cleaners, steam cleaning compounds, and de-scaling compounds.

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A New Plant to produce steel shipping pails for Vulcan Containers of Bellwood, Ill., will open this month in Vancouver, Canada. The pails are designed for shipping paints, chemicals, adhesives, oil and similar products.

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The New Sodium Chlorate Plant of American Potash & Chemical Corp., Aberdeen, Miss., will begin production late this year to supply chemicals to the

NEW PRODUCTS

(Continued From Page 86)

rapidly growing southern pulp and paper industry. Initial production rate will be 15,000 tons of sodium chlorate per year with provisions for possible expans on into production of perchlorate chemicals for high energy fuel applications.

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Two New Buildings will expand the facilities of the F. H. Maloney Company, 2301 Texas Avenue in Houston. One will be devoted to rubber finishing, warehousing and shipping; the other will house a production assembly line

for pipeline equipment including welding, metal fabricating and painting.

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Hexagonal Steel Panels welded together and strengthened by external supporting tension and compression members are being used for the world's largest circular building. Ten stories high and 384 feet in diameter, this dome-shaped building will serve as a regional tank car repair and maintenance plant for Union Tank Car Company in Baton Rouge, La.

Plastics

Emralon, a series of dispersions incorporating Du Pont's Teflon, has a curing temperature less than 300 F, making it possible to put a lubricating, corrosion-resistant film on wood, rubber,

plastics, light metal and other heat-sensitive materials. Available from Acheson Colloids Co., Port Huron, Mich., Emralon is sprayed, then dried by air, infrared or oven curing.

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Molded Rubber Products to be used b the petroleum and petrochemical processing industries will be available from Rubber Applicators, Inc., 7020 Old Katy Road, Houston. Additional equipment has been installed for the development of materials for specialized applications where corrosion and contamination are to be eliminated in storag or processing.

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Chemiseal, a rotating, corrosion-resistant mechanical seal made of plastics, seals under a variety of chemical service conditions, according to a bulletin issued by Garlock Packing Company. Chemiseals have proved durable when used with acids, alcohols, alkalies, hydrocarbons and related chemical compounds. The seals will operate for years in methanol, scrubbing oil, hot water, acetic acid or propionic acid. Additional information can be obtained by writing for Bulletin AD-164, Garlock Packing Company, 427 Main Street, Palmyra, N. Y.

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Thermokup, a new disposable plastic drinking cup is being manufactured by Crown Machine & Tool Company, Ft. Worth, from an insulating, feather-weight plastic. The plastic used is Dylite expandable polystyrene produced by Koppers Company, Inc., Pittsburgh. Because of the insulating properties of the plastic, the cup can be held comfortably in the hand while filled with boiling liquid.

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Dynel Fabric is being used to weather-proof the exterior surfaces of the reinforced plastic radomes of the North American defense line. Union Carbide's acrylic fiber provides a surface resistant to the effects of moisture, sunlight and ozone in the Arctic climate. The radomes are 55 ft. in diameter and weigh only 9000 lb.

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A Linear Polyethylene Buchner Funnel, designed for the filtration of corrosive slurries, is being produced by American Agile Corp., P. O. Box 168, Bedford, Ohio. Made of high density polyethylene, the funnel is equipped with an inclined bottom for drainage and a drain spigot.

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Condenser Tube Protectors made of fracture-proof Nylon are being made in a special construction to prevent turbulence. This is accomplished on the protector's inner wall which gradually tapers toward the discharge end, providing the thinnest possible wall at that point. The close conformity of the protector end with the inside diameter of the tube allows smooth water flow. Information is available from Crane Packing Co., 6400 Oakton Street, Morton Grove, Ill.

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Three-inch Hose made of Du Pont's Teflon is being manufactured by Raybestos-Manhattan, Inc., Passaic, N. J. Sold under the Flexlon name, it can

NEW PRODUCTS

stand temperatures up to 325 F. Because nothing adheres to the Teflon tube, it can handle caking solutions such as paints and varnishes.

Sealants

Stonlast, a new sealing material unaffected by extreme temperatures, expansion or contraction, has been developed by Stonhard Company, Inc., Philadelphia. It will form weather-tight seals for cracks and joints in concrete, brick, metal, wood and other building materials.

Surface Preparation

Sandblasting Efficiency has been increased with a longer-lasting venturi nozzle and a pulse air gun. The Norbite 1000-hour venturi nozzle increases sandblasting efficiency by 60 percent. Additional efficiency can be obtained by using a pulse air gun that interrupts the flow of air and sand at 5000 pulsations per minute. Remote controls for shutting off air and sand at the gun are also available from Clementina Ltd., 2277 Jerrold Avenue, San Francisco 24. Sales in the Southeastern and Southwestern states are handled by E. W. Oakes Co., P. O. Box 9102, Houston 11.

Tapes

Tapecoat, a protective coal tar coating in tape form, will be manufactured by a newly formed Canadian company in Rexdale, Ontario, known as Tapecoat Company of Canada, Ltd. The Tapecoat Company of Evanston, Ill., has supplied tape for the gas utility field, telephone companies and industry in general for protecting pipe, pipe joints, couplings, tanks, cable and conduit.

Tubing

Metal-ceramic Tubing to protect a thermocouple in a furnace has been developed to withstand thermal shock, erosion, corrosion, and flame impingement. Supplied by Haynes Stellite Co., Kokomo, Ind., the tube has been in service over six months in a sulphur dioxide gas line operating at temperatures up to 2300 F.

Valves

Penton—a product of Hercules Powder Co., known as a chlorinated polyether—is being used as lining for valves manufactured by Hills-McCanna Co., 4600 West Touhy Avenue, Chicago. The lining gives greater temperature and chemical resistance to valves.

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The University of Oklahoma Corrosion Control Short Course will be held March 31-April 12 at the North Campus, Norman.

MEN in the NEWS

John Blizard, Howard Coonley, James Gleason and **Ernest L. Robinson** will receive honorary memberships in ASME at the society's annual meeting in New York December 1-5. Mr. Blizard is director of research for Foster Wheeler Corp.; Mr. Coonley is a professional engineer; Mr. Gleason is board chairman for Gleason Works; and Mr. Robinson is former structural engineer for General Electric.

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Earl L. Wilson, Jr., is the manager of eastern district of the Koppers Company Metal Products Division. He will direct sales in eastern New York state, northern New Jersey and New England.

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Howard C. Pyle, president of Monterey Oil Co., has been elected president of the American Institute of Mining, Metallurgical and Petroleum Engineers. Other officers include **Dr. Joseph L. Gillson** as president-elect and **Thomas C. Frick,** vice president.

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James C. Richards, Jr., is the new vice president of sales at B. F. Goodrich Industrial Products Co.

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George E. Best has been appointed by the American Electroplaters' Society, Inc., as liaison member to the Inter-Society Corrosion Committee of NACE. Mr. Best has been nominated as vice president of NACE for 1959-60.

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Erich Krayer-Krauss, supervisor of industrial development and research for the Crown Diamond Paint Company, Ltd., Montreal, has been appointed a director of the company. He has served as corrosion consultant for the Hungarian government before working in industry and is a NACE member.

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A. F. Beale, Jr., has been appointed director of chemical research at Dowell's new research and development department in Tulsa. A NACE member, Mr. Beale has been teaching at the Universities of Richmond, Wyoming, Michigan and Toledo prior to joining the Dowell staff in 1953.

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Newton R. Crum is the manager of Lunkenheimer Company's Los Angeles office. **J. Paul Scherer** is a new sales representative of the company in the New York City office. The company manufactures valves.

•

Dr. John Chipman, professor of metallurgy at MIT, has been elected president of the Metallurgical Society of AIME. **Dr. Carleton C. Lond,** research director for Zinc Smelting Division of St. Joseph Lead Co., Monaca, Pa., was elected vice president of the society.

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Joseph V. Kidd has joined the F. H. Maloney Company of Houston as sales engineer for the Houston area. He will serve pipeline and industrial accounts.

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Jerome J. Hargarten has been appointed service manager of the Chlorine Products Division for the Du Pont Company's Electrochemicals Department. He will direct activities of technical representatives and will co-ordinate metal cleaning work in the field.

TECHNICAL TOPICS

Controlling Corrosion of

OFFSHORE PLATFORMS

and some typical costs
on a tender-type installation*

Abstract

After considering in general the problem of protecting an offshore platform in seawater, some suggestions are given concerning proper design. A successful vinyl painting system is described and recommendations are made concerning specifications, inspection during and after initial painting. Methods used to protect old equipment are listed and data are given on an example of 5-year corrosion control costs on an offshore rig.   **5.4.5**

OFFSHORE Steel platforms are subjected to the same corrosive conditions as steel pilings in sea water and are expected to last from 35 to 50 years. Corrosion coupons and weighed samples taken from pilings show a typical corrosion profile. Established corrosion rates in the respective zones without adequate corrosion control measures are 0 to 10 mpy below water; 25 to 40 mpy in the splash zone; and 3 to 5 mpy in the atmospheric zone. Steel replaced offshore costs over three times as much as steel installed onshore; that is, about $.50 per pound offshore compared to $.14 per pound onshore. Consequently, it is necessary that corrosion be mitigated so the useful life of a platform is equal to the economic life of the wells.

Corrosion in the submerged zone is attributed to galvanic corrosion around welds, solution of steel resulting from stray currents and reaction between steel and the chemicals in the electrolyte-laden, low resistivity water. Corrosion in the splash zone results from galvanic action resulting from small differences in the metal and from potential differences at different levels apparently resulting from varying oxygen concentrations. Corrosion in this zone is aggravated by mechanical damage from floating debris and boats. Corrosion in the atmospheric zone results from reaction between oxygen in the air and the steel in the presence of salt water spray or water condensed from the humid atmosphere.

Cathodic protection is the most suitable means of protecting the submerged areas from corrosion. Because of the extremely low resistivity of seawater, bare steel can be polarized within a reasonable time with galvanic (magnesium) anodes calculated to provide an initial current density of 5 to 10 milliamperes per square foot, which is later reduced to about 3 milliamperes per square foot. Initial current density required depends upon the geographical location of the platform. Cathodic protection systems

are designed to provide protection for two to two and one-half years.

A barrier coating is indicated for the splash zone because it cannot be protected cathodically. Ordinary paint films will not suffice because of the mechanical damage and difficulty of maintaining them against the almost constant wetting. A considerable capital investment for a more permanent type of protection in this zone can be justified. A number of wrappers including tapes, glass fiber-plastic materials and rubber have been tried. Several companies use additional steel thickness, but Continental prefers to use 18-gauge economy Monel sheathing, welded into place at an average cost of $5 per square foot installed. Recent corrosion damage measurements in the splash zone of platforms by two offshore operators has indicated that properly applied Monel sheathing will control corrosion in this area more effectively than the steel doubler plating or the various tapes.

Because of the greater area involved and the less severe corrosive environment, however, less expensive barriers than Monel must be used in the atmospheric zone. Because this zone also is the most accessible, coatings requiring periodic maintenance can be utilized. Frequent maintenance cannot be tolerated because of the high cost of offshore coating work (about $1000 to $1200 per day for boats, labor, equipment and materials) and the high lost time factor for weather (15 to 30 percent depending upon the season and location).

Good Design Is Essential

A discussion with construction engineers will assure that the best design for operational efficiency and corrosion control is adopted. Jackets built of tubular members only have no "blind" spots difficult to protect cathodically. Tubular members in the splash zone (except for the expendable boat landings) minimize the difficulty in applying Monel sheathing. Because corrosion rate is greater in this zone, the number of structural members should be the minimum for necessary strength. This can be accomplished to a degree by moving horizontals below water where they can be protected by cathodic protection or

above the splash zone where they can be maintained with coatings.

The design should avoid difficult-to-paint areas in the atmospheric zone. Plates should cover corners where wide flange beams are connected with tubular members and seal welding included for deck support angles. Total surface areas can be reduced to a minimum by using as many tubular members as strength requirements permit and by using a few large rather than many small members. All handrails, gratings for cellar decks and other small items which cannot be maintained easily by painting should be galvanized.

A review of the environment during and after drilling period in the atmospheric zone of drilling platforms shows that a coating for this zone must exhibit the following properties:

Resist undercutting around failed areas or holidays, high pH (12.5-13.5) mud, lifting tendency of drying mud, oil and grease spills, abrasion from accidental blows with tools of all types, sunlight with resultant alligatoring, chalking and checking or cracking.

Be quick drying.

Have non-permeable film that can be maintained economically by periodic maintenance.

Preferably have fire-resistant dry film which is pleasing in appearance and

Be economically priced.

Vinyl Materials Are Suitable

Among various types of maximum-resistance coatings suitable vinyl materials (modifer consisting primarily of vinyl acetate and vinyl chloride) offer the most promise. The vinyls have the necessary chemical resistance and, being a lacquer type can be rejuvenated by infrequent overcoating with refresher coats of the vinyl or solvent, which characteristic lends them to periodic maintenance. However, vinyls have poor adhesion to steel, low film build per coat and comparatively poor resistance to abrasion so they require very good surface preparation and a number of coats with different individual properties to assure a complete, satisfactory film. To overcome these deficiencies, vinyls usually are applied in "systems" over "white" sandblasted surfaces.

A suitable five-coat vinyl system for offshore platforms is:

An acid primer to prevent early rusting of cleaned surfaces and improve adhesion.

One "build" coat containing an inhibitive pigment such as red lead or red iron oxide and flake mica to increase the film build;

One build coat containing flake mica to increase film build.

Offshore Platforms—

(Continued From Page 93)

One "mastic" coat containing flake mica and fibrous asbestos to increase the film and abrasion resistance;

And a "thin-film" finish coat to bind the coating system together, afford a smoother more easily cleaned surface and the desired finish color.

This coating system has a thixotropic nature which makes it cover better than some of the other vinyl systems on edges and welds, which is very important for the welded steel offshore platforms. Furthermore, this system has given good service offshore in the past.

Application specifications should describe the coating in minute detail, including any expected problems in the application of the various coats, drying time, film thicknesses, ambient condition limits in regard to humidity and temperature, application equipment required and application techniques. Colors of intermediate coats should differ so that full coverage can be assured and so that misleading indications by rust colored intermediate coats will be minimized in maintenance.

The current tax structure is such that capital investment for painting new installations is not always as attractive tax-wise as later paint maintenance, the cost for which can be considered an expense item. Consequently, an economic analysis should be presented to management to obtain proper funds for the proposed paint work. The engineer should remember that an additional coat of paint can be applied at much less cost during the initial work than at any time thereafter. This is no time to economize on coatings because a cheaper paint is not necessarily more economical. Also a proper coating system will prevent possible metal loss before maintenance begins.

Continuous Inspection Is Wise

Whether the painting is done by contract or company personnel, continuous inspection is very wise. Expected to be more conscientious than contract workers, even company personnel sometimes may try to coat "just a few more square feet" when the ambient conditions are not proper, or to neglect surface preparation. The best surface preparation and coating application specifications are of no benefit unless they are strictly followed. Good inspection instrumentation is required and should include such items as sand sieves, coating thickness gauges, holiday detectors, magnifying glasses and a camera.

After the painting is completed, the installation should be in excellent condition. However, it will not stay this way without diligence on the part of the corrosion engineer. A system of regular inspection, with detailed records of the conditions of the various sections at the time of each inspection, should be adopted. The first inspection is very important and should be scheduled soon after the installation is placed in service. No matter how good the coating job appears, it will not be perfect and holidays will become apparent soon after the environment becomes corrosive. The coating touch-up and spot maintenance should begin as soon as practical and before minor corrosion problems become serious.

Initial application deficiencies usually will be indicated by small rust stains within three to six months after the equipment is placed in service. Spot maintenance often can be done on operating units, but major maintenance painting usually must be scheduled during shut down periods. Specifications for touchup work are as important as and should be as detailed as initial specifications.

Maintaining Old Equipment

Several steps are required in organizing an effective paint maintenance program for old or corroded equipment. Most corrosion engineers prefer to conduct a thorough personal inspection of the installation first. This inspection should include determination of the physical condition of the equipment itself and of the existing coatings. The engineer should concern himself first with those areas which have suffered the greatest corrosion damage. He may find certain "built-in" corrosion problems in the form of structurals, stiffeners and brackets which are so shaped that they cannot possibly be maintained with coatings. He may also find in plants or refineries that plant layout is such that corrosion in some areas actually is promoted by corrosive solids, vapors, fumes and spray carried by prevailing winds from other areas in his own or from nearby operations. If this is the case, painting alone may not be enough.

Under most circumstances, it will be impossible to justify major alterations in the layout of an operating installation solely to reduce corrosion. How-

Offshore Platforms—

(Continued From Page 94)

ever, shelters, sheds or walls can be erected to minimize this problem. Also, it may be economically expedient either to replace certain structural members and other items immediately or to allow them to deteriorate until they require replacement. Replacements, of course, should be designed so that they can be maintained easily or be of such materials that they will resist corrosion. In addition to the replacement of some items, seal welding and flat cover plates should be considered just as they are for new installations.

Detailed Records Necessary

Detailed records of paint maintenance costs in all areas should be maintained so problem areas can be detected early. Such data are invaluable when planning a maintenance program, estimating costs for budget or other purposes, or when considering new installations. Also, exposure tests should be continued in order to determine whether changes in coating systems for some areas are indicated and to assay the qualities of newly-developed coatings.

After initial touchup on new installations, paint maintenance falls into the simple routine of inspections, recommendations, exposure tests, cost evaluation and specification. However, each maintenance job should be considered on its own merits in regard to economics and the best approach to corrosion control. Also, an effective paint maintenance program includes continuous training of all personnel involved in the selection and application of coatings to insure that the finished coatings are not damaged by abuse.

Economics of Offshore Rig Coatings

Initial corrosion control costs cannot be determined exactly because of the all inclusive nature of the contract, but the data given in Table I are reasonably accurate for a 52 by 106-foot tender-

type platform in 50 feet of water in the West Delta area:

Recent inspections indicate that the platform will not require additional coating touchup until mid-1959 which should suffice through 1960. During mid-1961 it is expected the platform will require cleaning, coating touchup and a complete refresher coat at approximately the initial coating cost.

The following estimates have been made of the predicted coating cost for the first 5½ years' service:

Estimated cost of coating touch-up June, 1959 (5 days work @ $1200) .... $ 6,000

Estimated total coating cost first 5½ years 22,052

Estimated average cost per square foot first 5½ years..... 77.4¢

Estimated average cost per sq. ft. per year first 5½ yrs...... 14.1¢

The various steps that should be taken in establishing and continuing a paint maintenance program need not be followed in the sequence shown, because the sequence will be dependent upon the particular situation:

1. Assay the corrosive environment.
2. Design for corrosion control.
3. Plan layout to minimize corrosion.
4. Review experience of others.

5. Select coatings for particular corrosion and physical problems.
6. Select and prepare complete, detailed surface preparation and coating application specifications.
7. Select and "Know Your Applicator."
8. Inspect coating work during application and when completed.
9. Inspect and repair initial coating deficiencies soon after equipment is placed in service.
10. Established a regular inspection, coating evaluation and touchup program.
11. Maintain complete detailed inspection and cost records.
12. Review records periodically to evaluate coatings and paint maintenance program.

Acknowledgment

I express my appreciation to the Continental Oil Company for allowing me to take part in the University of Oklahoma 1958 Corrosion Control Short Course. I also thank Jack Dart, Products Research Service and G. W. Cooper and Earl D. Gould, of Continental Oil Company for the assistance given in collecting data for this article.

TABLE 1—Anti-Corrosion Maintenance Costs On a Tender-Type Offshore Platform

Total cost of platform installed at West Delta Block 45 "B" location	$359,371
Cathodic protection cost submerged zone (29,000 sq. ft. @ $0.064)	$1,850
Cost of Monel for splash zone (1536 sq. ft. @ $5.00)	7,580
Painting and miscellaneous cost for atmospheric zone:	
Galvanizing	$ 1,500
Deck Treatment	1,700
Painting (28,560 sq. ft. @ $0.41)	11,700
Total for atmospheric zone	$14,900
Total for corrosion controls	$24,330
Percent of total cost for initial corrosion controls	6.77
Cost for coating touch-up September, 1956	$ 4,352
Cost of anode replacement August, 1957	$ 1,850

Comparing the Corrosion Resistance of Wrought Iron and Steel*

Discussion by F. N. Speller, Consultant, Pittsburgh.

HISTORY apparently repeats itself in metallurgy as in other human affairs. The paper by Mr. Best on "Iron Silicate Network Helps Wrought Iron Resist Corrosion"[1] in the February, 1958 issue of CORROSION attempts to revive the traditional assumption that wrought iron is intrinsically more durable than other ferrous metals such as are used in manufacture of pipe, but gives no supporting data. As this question was thoroughly investigated by me and my associates from 1902 to 1925 and many data obtained during that period and later are on record, I feel it a duty to try and fill in some references with the conclusions that were based on authentic evidence on water and underground corrosion of pipe, for those who are interested in reviewing what has been done on this subject.

There is such a great difference in non-metallic contents of the soft steels and wrought iron that one would expect to find a decided difference in corrosion pitting rate if the non-metallic or "slag" contents is an important factor. The non-metallics in wrought iron, about 2½ percent, consist mainly of oxides of iron (the silicon is reported to be about 0.15 percent).

Most of the available data on relative corrosion of ferrous metals from 1888 to 1920 were summarized in condensed form in Chapter VII, 2nd Edition, of my book on "Corrosion."[2] This chapter was purposely omitted from the 3rd Edition, 1951, but the 2nd Edition (1935) is, I believe, available in most of the larger public libraries. These data are from laboratory and service tests on water, steam and vent pipe in various localities.

Early in this century some leading manufacturers made both wrought iron and steel pipe in about equal amounts and these sometimes became mixed in stocks. They were faced with the question of expanding production. Wrought iron was favored by many pipe fitters because it was easier to thread than steel with the crude hand dies of that time. The most important question in mind, however, was, "Is there anything in the idea that wrought iron is intrinsically more durable?" After a thorough investigation it appeared that this notion was based mainly on visual observations under atmospheric exposure where the iron apparently had some advantage in certain places which, however, did not apply under other conditions as in water or soil. Copper steel later proved to last longer than wrought iron, ingot iron, or steel under atmospheric exposure.

Table XLIX[2] contains many comparisons of wrought iron and steel in hot water pipe which were accidentally coupled together in the same line and thus were subjected to identical conditions of service for various periods. Over 100 of such cases were found without any consistent or material difference in the deepest pitting which was used as the criterion of useful life expectancy.

Table L, 2nd Edition,[2] is a summary of results of many tests of these metals (and others) in service lines where pieces of bare commercial pipe were installed together in the same line, in hot water, steam return and in vent pipe systems. Differences in rate of pitting were evidently due to variations in flow, temperature and composition of the fluid contents. Details of these important factors could not always be obtained but all materials were subject to the same service variables.

Many other authentic tests and observations under similar conditions of service which were made prior to 1935 (with which I am personally familiar) are also described in Chapter VII.[2] Few, if any, of these showed a pronounced difference in depth of deepest pitting between wrought iron and steel under strictly identical conditions.

The many tests cited above, I believe, show conclusively that there is no material difference between low alloy steels, mild carbon steels, wrought iron and ingot iron in water or underground. References are given (page 266 of 2nd Edition of my book on "Corrosion"[2]) to similar extensive investigations, between 1908 and 1911, by Professors Howe and Stoughton, Columbia University, and by Dr. W. H. Walker at Massachusetts Institute of Technology, Cambridge. In the light of the facts developed by their investigations, they could find no sound basis for the impression which was then prevalent, that wrought iron was intrinsically superior to steel in corrosion resistance.

Propaganda rather than tangible data evidently had much to do in establishing these early opinions. If there are any supporting data on improvements, in manufacture of wrought iron, it would be welcome, but the fact that the environment rather than metal composition is the controlling factor, is now well established and generally recognized.

In England many comparative tests on mild steel, ingot iron, and wrought iron in sea water were made by the Committee on Corrosion of British Iron and Steel Institute. Results were summarized in 1940 by Dr. J. C. Hudson (Official Investigator of the Committee) in his book.[3] In a later paper Dr. Hudson reports further work on "Corrosion of bare iron or steel in sea water."[4] In the synopsis he states, "There is little, if any, difference in the corrosion rates under these conditions of ordinary unalloyed ferrous materials, such as mild steel, ingot iron, or wrought iron."

Underground we now have much more data on this question based largely on the exhaustive work centered at National Bureau of Standards between 1922 and 1955, summarized in Cir. 579—1957.[5] Of more than 22,000 specimens buried in 1922 and 1924 in 47 soils, after 9-12 years the maximum penetration varied from 20 to 150 mils in both 1½-inch and 3-inch pipe, clearly showing that variations in soil condition dominated. The pitting factor (ratio of maximum depth of pit to average penetration) varied from 1 to 25.5. The student may consult extensive tabulated data in this circular if interested in details. The effect of composition is well summed up with respect to pitting on page 31, as follows: ". . . the difference between the maximum penetration for wrought iron and Bessemer steel is not sufficient to show positively a difference in the rates of corrosion of these materials for either the 1½ inch or the 3 inch specimens."

Now, as to the hypothesis that the high non-metallic inclusions (cinder or slag) in wrought iron interferes with the direct penetration of corrosion, the fact remains that there is no pronounced or consistent difference in penetration in water or soil. The cinder or slag may interfere more effectively when the iron is rolled crosswise and lengthwise as in rolling plates, but in any case the effect is probably neutralized more or less by acceleration of the rate due to the cathodic nature of the cinder. Moreover the arrangement of the slag is obviously irregular with frequent loopholes.

It would be interesting to learn whether the more resistant zones in wrought iron described by Chilton and Evans[6] have been found in the newer wrought iron described by Mr. Best. The slag theory seems to have been discarded in England, where some puddled iron is still made.

Welded wrought iron and steel pipe is made from skelp rolled lengthwise so that the slag is mostly in the form of strings rather than wide flakes, in which form it would not be a uniform barrier to corrosion. The micro-sections show frequent loopholes between slag sections.

The slag contains only a small amount of silicate of iron (the silicon content of wrought iron runs about 0.15 percent). However, the iron oxide in the "slag" gives the metal a rougher surface than steel which improves adherence of paint and may afford some resistance to fatigue. Hence the slag in wrought iron has some advantages, but resistance to corrosion penetration of welded pipe is evidently not one of them.

References

1. Iron Silicate Slag Network Helps Wrought Iron Resist Corrosion. E. P. Best. *Corrosion* 14, No. 2, 118-120 (1958) Feb.
2. F. N. Speller. Corrosion, Causes and Prevention, 2nd Edition (1935) McGraw Hill Book Co., New York.
3. J. C. Hudson, Corrosion of Wrought Iron and Steel (1940) Van Nostrand Co.
4. J. C. Hudson, Jr. Iron and Steel Institute, 1950, Page 125.
5. Underground Corrosion. Circular 579. April 1957, National Bureau of Standards, Washington, D. C.
6. J. P. Chilton and U. R. Evans, "Corrosion Resistance of Wrought Iron," *J. Iron and Steel Institute*, Vol. 181, October 1955, Pages 113-122.
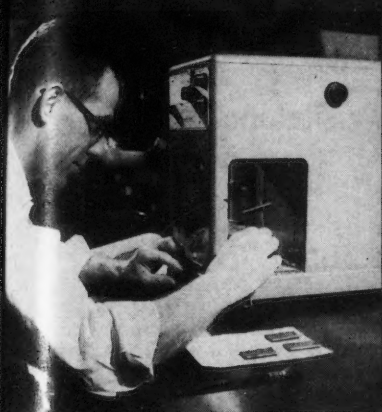
1 Analytical weighing of specimens prior to testing
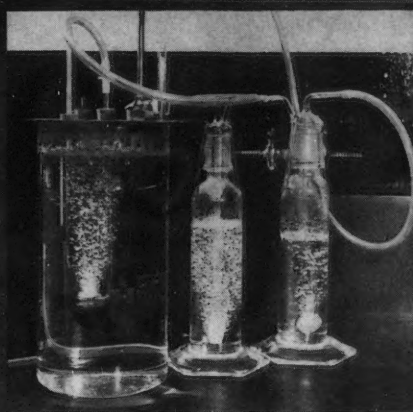
2 Steam condensate corrosion test
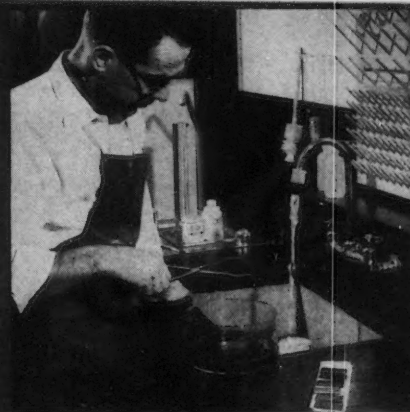
3 Cleaning specimens with inhibited hydrochloric acid
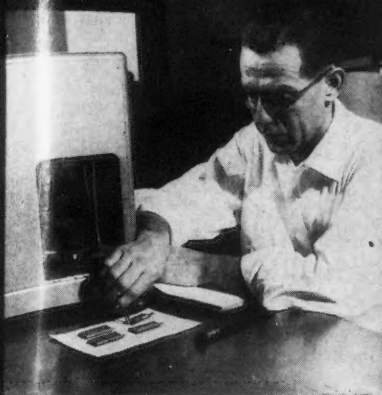
4 Second analytical weighing to determine corrosion weight loss

5 Calculation and statistical analysis of laboratory test results
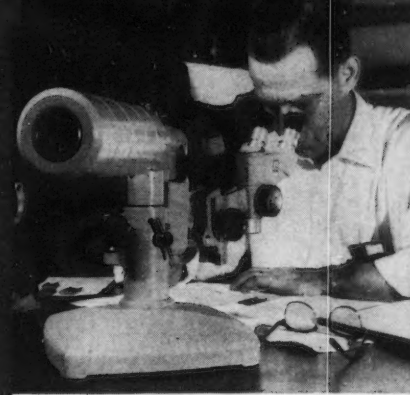
6 Final examination of specimens under low power magnification

Extensive testing program proves new 4-D Wrought Iron more corrosion-resistant than ferrous substitutes

Test results from the Byers Research Laboratory lend documentary support to the superiority of new 4-D Wrought Iron—over standard Wrought Iron as well as ferrous substitutes.

Convincing case-history service records are now further substantiated by the conclusive findings of our metallurgical staff. Some typical results of this testing program are presented in the chart at right.

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BYERS WROUGHT IRON

Comparative Analysis of 4-D Wrought Iron Corrosion Tests

Tests	4-D Wrought Iron	Standard Wrought Iron	Ferrous Substitutes
Severe industrial atmospheric continued exposure 17 years	Corrosion weight loss 540 grams/sq. ft.	Corrosion weight loss 655 grams/sq. ft.	Not included in test
Steam condensate return line	*At least 25% greater corrosion-resistance than standard Wrought Iron	No failures 10 years (still in service)	Complete failure after 2 years
Aerated salt water—5 weeks (Short term test—points indicate 4-D Wrought Iron curve flattening out at much lower rate of attack)	Corrosion weight loss 146 mg/sq. in.	Corrosion weight loss 170 mg/sq. in.	Corrosion wt. loss 226 mg/sq. in.
Brine piping	*At least 25% greater corrosion-resistance than standard Wrought Iron	No failures 23 years (still in service)	Complete failure after 7 years
Salt water, Gulf of Mexico ¼ inch plate—17 years	Corrosion weight loss 4 mills/years (minimum plate thickness now 3/16") Still in excellent condition	Not included in test	Corrosion weight loss 30 mills/years; plate badly pitted, perforated
Downspout	*At least 25% greater corrosion-resistance than standard Wrought Iron	No failures in 29 years (Still in service)	Complete failure after 18 years

*In this application no long term test data yet available on 4-D Wrought Iron. Results shown are derived from short term tests.

Wrought Iron—

Reply by E. P. Best, A. M. Byers Co., Pittsburgh:

As pointed out by Dr. F. N. Speller, this is an old and tedious argument. Generally speaking, published interpretations of laboratory test data have not been flattering to wrought iron, whereas many authenticated service records distinctly show an unusual longevity for the material, as well as its superiority over other metals in identical environments.

However, various interpretations of such laboratory test data are possible, as J. Lyell Wilson, formerly research director of the American Bureau of Shipping, New York, points out in his discussion of wrought iron corrosion.[1] Mr. Wilson notes the following example: "A startling example of contradiction between corrosion test results and service experience is exemplified in the record of the wrought-iron pipe piling used for pier supports in the old Fort Mason Dock in San Francisco which was built in 1884. These same wrought iron piles were found to be in such good condition in 1931 that they were again used in building a new pier for the San Francisco Marina Yacht Harbor. They are now, after 69 years of service, in a good state of preservation and still serving the same useful purpose although some steel beams and tie rods added to the original Fort Mason Dock had almost entirely disintegrated from corrosion by 1931 after only 20 years of service. Ironically enough, however, one of the steel companies subjected samples of the wrought-iron piles and of the steel beams to corrosion tests and the results showed no advantage for the wrought iron over the steel. Had such tests been made prior to the original construction an unwise choice of material undoubtedly would have been made for both piling and superstructure."

Significant is Mr. Wilson's statement: "It is far more difficult to understand why something is not being done to improve methods of testing to produce better correlation between test results and actual service with particular reference to wrought iron."

The author's company is now engaged in research aimed at answering Mr. Wilson's question.

Reference

1. How Does Wrought Iron Stand Up in Corrosive Marine Service? By J. Lyell Wilson. *Marine Eng.*, Feb. 1954.

INDEX TO CORROSION ABSTRACTS

3. CHARACTERISTIC CORROSION PHENOMENA

3.7 Metallurgical Effects

3.7.2, 6.4.2

The Effect of Small Amount of Beryllium on Aluminum-Magnesium Alloys. TOYOJI USHIODA, OSAMU YOSHIMURA AND SHOICHIRO MASHIYAMA. *Light Metals* (Japan), No. 27, 29-33 (1957) Nov.

It is generally recognized that a small amount of beryllium gives various beneficial effects to sand cast materials of aluminum-magnesium alloys. To acquire the industrial effect of a small amount of beryllium in aluminum-magnesium alloy cast slab for wrought materials and its sheet, the authors tested the following: (1) Oxidation loss at melting operation, (2) Casting crack and flatness of slab surface, (3) Grain size, (4) Mechanical properties, (5) Corrosion resistance, (6) Black film formed during heating operation. The results are as follows: Addition of 0.005% beryllium to aluminum-magnesium alloy exceedingly decreases casting crack and the surface of continuously cast slab becomes considerably flat and also the black spot on slab surface disappears. Adding beryllium in these amounts is not industrially effective to mechanical properties and corrosion resistance. On the other hand, oxidation loss at remelting operation and black film formed during heating of slab or sheet is considerably prevented by beryllium. (auth.)—ALL.   15119

3.7.2, 3.2.3

The Effect of Trace Elements on Scaling Behavior of Heat-Resistant Alloys. H. PFEIFFER. *Werkstoffe u. Korrosion*, 8, 574-579 (1957) Oct.

Review of effect of trace additions, such as cerium and cadmium, on scaling behavior of resistance materials, such as nickel-chromium, nickel-chromium-iron and iron-chromium-aluminum alloys. Experimental study was made of effect of controlled cerium additions on a 27

chromium-5 aluminum iron-base alloy. Theoretical discussion of oxide film phenomena and effect of addition elements on adhesion of scale formed and of effect of aluminum additions on scaling behavior of 33/20 nickel-chromium iron-base alloys is included. Study was made of simple and complex oxides formed in oxidized, adherent layer.—INCO.
14999

3.7.2

Effects of Trace Elements on Embrittlement of Steels. K. BALAJIVA, R. M. COOK, AND D. K. WORN. *Nature*, 178, No. 4530, 433 (1956) August 25.

Factors controlling embrittlement of steels are discussed. Incomplete study of effect of trace elements in three nickel-chromium steel showed that steels can be made with impact properties unaffected by exposure at 450 C and that effects of each of trace elements normally present in commercial materials can be assessed by studying high-purity steels to which these trace elements are added in controlled amounts.— INCO.   12762

3.7.2, 6.4.2

Effect of Chromium Additions on the Microstructure of Aluminium-Zinc-Magnesium Alloys. (In French.) P. BRENNER AND M. SCHIPPERS. *Rev. Met.*, 53, No. 8, 627-637 (1956) August.

The tendency to stress corrosion of aluminum-zinc-magnesium alloys has been eliminated by the application of alloying techniques such as strict control of composition, proper heat treatment and addition of small quantities of a stabilizing element, of chromium in particular. To investigate the mechanism of this latter phenomenon samples were prepared from three alloy groups of various zinc and magnesium contents, with and without chromium additions, by continuous casting, rolling and precipitation heat treatment. The samples were subjected to electrolytic polishing and, in some cases, to anodizing. Microscopic investigation of the surfaces thus treated revealed that addition of 0.2% chromium has caused a coagulation of the precipitates at the grain boundaries and, at the same time, has brought about uniform precipitation within the grains themselves. This type of microstructure is known to develop in aluminum-magnesium alloys when subjected to step-wise quenching and is accompanied by increased resistance to stress corrosion. It is, therefore, assumed that the improved stress-corrosion properties of aluminum-zinc-magnesium alloys containing chromium are due to the changes in its microstructure induced by this addition.—ALL.   12737

3.7.2, 3.2.3, 5.3.4

Behavior of Copper in Steel During Scaling and Its Effects on Hot-Dip Zinc-Coating of Steel Wires. (In German.) CLEMENS EISENHUTH, WOLFGANG GRUHL, WERNER PAPSDORF AND IRMGARD EISENHUTH. *Stahl und Eisen*, 77, 354-359 (1957) March 21.

Investigation of copper distribution in steel specimens containing 0.7% carbon and 0.38% copper as dependent on the degree of scaling. Behavior of the copper

when annealing in an argon atmosphere. Effect of the molten zinc on copper content in the marginal zone.—BTR. 14284

3.8 Miscellaneous Principles

3.8.4, 6.3.21

Effects of Thick Oxides on Germanium Surface Properties. M. LASSER, C. WYSOCKI AND B. BERNSTEIN. *Phys. Rev.* (II), 105, No. 2, 491-494 (1957).

Oxides grown on germanium by heating in oxygen inhibit interaction between the germanium and the ambient atmosphere. The decay time of the DC-field effect increases with increasing thickness of the oxide formed, indicating that the states associated with the oxide lie principally on its outer surface. The decay time decreases, however, in the presence of water vapor, I, or ammonia in the ambient, probably owing to an increase in the d of states on the outer surface of the oxide layer. Desiccation lengthens the decay time greatly. If the oxide layers are of the order of 0.25μ in thickness, the DC-field effect displays no measurable decay and the electrical properties of the underlying germanium are unaffected by a vapor as active as I.

The surface underneath a thick oxide is strongly n-type and has a low value of surface recombination velocity.—MA.

15139

3.8.4, 6.2.5

Physical Properties of Monolayers Adsorbed at the Solid/Air Interface: Pt. 3. Friction and Durability of Films on Stainless Steel. R. L. COTTINGTON, E. G. SHAFRIN AND W. A. ZISMAN. U. S. Naval Res. Laboratory, Dec., 1957, 18 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131493).

Recent investigations of the physical properties of condensed monolayers of polar paraffinic compounds adsorbed at the glass/air interface provided insight into the friction-reducing, anti-wear and load-carrying properties of such films. This study was undertaken to determine whether results would be similar when the two rubbing surfaces were of stainless steel instead of glass and stainless steel. Durability of the condensed solid monolayer was low after the first few traverses of a stainless steel ball on a steel platen. The lesser protection afforded by condensed films resulted from the greater tendency for steel asperities to cold weld with steel than with glass. This exemplifies the general conclusion that the protective value of a condensed monolayer decreases as the solid solubility of the two rubbing surfaces increases.—OTS.

15239

3.8.4, 4.3.2, 6.3.20

Reaction Rate Study of the Dissolution of Low-Hafnium Zirconium in Hydrofluoric Acid Solutions. G. R. HILL AND T. SMITH. First Nuclear Engineering and Science Congress, 2, 63-69 (1957).

The rate at which zirconium dissolves in hydrofluoric acid solutions studied by tracer methods and found to be dependent on free acid concentrations alone. Temperature coefficient averages 3.34 k-cal per mole for high stirring rates. The most likely mechanism of the slow step is diffusion of hydrofluoric acid to the zirconium surface, but three others are also considered. 11 references.—MR.

15314

3.8.4

Corrosion as Affected by a Zone of Metal Emerging from the Corrosive. P. HERSCH. *Nature*, **180**, No. 4599, 1407-1408 (1957) Dec. 21.

Water-line corrosion is caused and salt-spray corrosion is facilitated by the easy access of oxygen to the metal through a 3-phase boundary between metal, electrolyte and atmosphere. Experiments are described which give some insight into mechanism of arrival of oxygen at such menisci and its electro-dissolution. Part played by various zones is demonstrated by coupling a strip of relatively inert metal, such as platinum, silver, nickel stainless steel or titanium as cathode with a large area of a moderately base metal, such as lead, cadmium or iron as anode in an electrolyte. Curve is given of the system nickel/potassium hydroxide/lead.—INCO.

15299

3.8.4, 6.3.6

The Structure of Oxide Films Formed on Smooth Faces of a Single Crystal of Copper. W. W. HARRIS, F. L. BALL AND A. T. GWATHMEY. Uni. of Virginia. *Acta Metallurgica*, **5**, 574-581 (1957) Oct.

Oxide films, which were formed on the (311), (111) and (100) faces of a single crystal of copper heated at 150 C, were removed electrolytically from the

copper and examined with an electron microscope. The structure of the oxide was found to be related to crystal face of the copper and three types of structure were observed. On each face the film consisted of: (1) small nuclei from less than 20 to 80 A in diameter, (2) regularly shaped masses of oxide from 80 to 3000 A in diameter, and (3) a crystalline base film initially unresolvable with the electron microscope. (auth.) —NSA.

15296

3.8.4, 3.5.8, 3.5.9, 6.3.15

Research on the Effects of Stress, Strain and Temperature on the Eutectoid Decomposition of Titanium Alloys. A. W. GOLDENSTEIN, A. G. METCALFE AND W. ROSTOKER. Armour Research Foundation. U. S. Wright Air Development Center, U. S. Air Force, November, 1957, 72 pp. Available from Office of Technical Services, Washington 25, D. C. (Order PB 131610).

This work yielded data for evaluation of the combined influences of time, temperature, and stress on the rate of embrittlement of titanium-chromium alloys. Three titanium-chromium alloys were forged in the alpha-beta range to give six systems with controlled amounts of each phase. Isothermal transformation at 400, 500 and 600 C of each of the systems was followed by resistivity, X-ray diffraction, elastic modulus measurements and metallography. Reactions occurring in the transformation were identified where possible. This transformation study was repeated under a stress which produced 1% creep in 1000 hours. Acceleration of four to seven times in the rate of transformation occurred in the action of this stress. Complete tensile test data were obtained at all stages of transformation and plotted on T-T-T diagrams. These revealed that the formations of omega and $TiCr_2$ are the embrittling reactions. The eutectoid temperature in the titanium-chromium systems was determined as 670 C, plus or minus 5 C.—OTS.

15279

3.8.4

Investigation of Oxidation Resistance of Titanium and Niobium Borides. V. S. NESHPOR AND G. V. SAMSONOV. *J. Applied Chem. USSR* (Zhur. Prikladnoi Khimii), **30**, 1584-1588 (1957) Nov. (In Russian.)

Oxidation resistance of titanium boride and niobium boride and their alloys forming a continuous series of solid solutions was studied with borides of roentgenographic density $TiB_2 = 4.53$ and $NbB_2 = 7.08$ g/cm³ and the lattice parameters of titanium and niobium borides a = 3.028 A, c = 3.224 A and a = 3.082 A, c = 3.278 A, respectively. —NSA.

15392

3.8.4

Type of Ion Migration in a Metal Oxide (Zirconium/Zirconium Dioxide System.) O. FLINT AND J. H. O. VARLEY. *Nature*, **179**, No. 4551, 145-146 (1957).

Two zirconium electrodes were separated from an intervening compact of sintered zirconium dioxide by filter-papers soaked in alizarin-sulfur, which turns yellow in the presence of nascent oxygen from hydrogen peroxide but then still gives a red color with Zr^{4+}. With this assembly in dry nitrogen, a DC voltage of ~1000 V/cm was applied for several hrs. The filter-paper in contact with the positive electrode turned yellow, while the other paper remained red; there was some corrosion of the metal surfaces. It is hence suggested that oxygen ions move in zirconium and migrate from the negative to the positive

electrode. It seems that the zirconium dioxide compact contains excess oxygen. At the negative electrode a deficiency of oxygen ions is created, so that the cathodic zirconium surface is enriched in Zr^{4+}. These reactions do not occur in the absence of an electric field.—MA.

14111

3.8.4, 3.5.6, 3.2.3

Diffusion and Oxidation of Metals. MASSOUD T. SIMNAD. General Dynamics Corp. *Ind. and Eng. Chem.*, **49**, 617-626 (1957) March.

A review is presented which includes theory of diffusion, volume self diffusion, chemical diffusion in substitional alloys and interstitial alloys, grain boundary and surface diffusion and oxidation of metals and alloys. 361 references.—NSA.

14140

3.8.4, 3.5.8

A Study, by Means of the Russel-Effect, of the Influence of Mechanical Stresses on Metal Surfaces. (In French.) C. BERGER. *Metaux: Corrosion-Industries*, **32**, No. 381, 185-190 (1957) May.

Secondary electron emission from aluminum subjected to mechanical stresses was investigated. It was observed that, when bending a sample, the outward face, which is subject to a tensile stress, affected the photographic plate, on which the sample was placed, while very little blackening due to the inside face was noticed. Such behavior of the sample is attributed to the disruption of the oxide film on the outside. The phenomenon described is correlated to the Russel-effect and it is said that hydrogen peroxide formed as a result of re-oxidation according to the reaction: metal $+ O_2 + H_2O \rightarrow MeO + H_2O_2$, may be the primary factor affecting the photographic plates.—ALL.

14213

3.8.4, 6.3.10, 3.5.9

High Temperature Oxidation of High Purity Nickel Between 750 and 1050 C. EARL A. GULBRANSEN AND KENNETH F. ANDREW. *J. Electrochem. Soc.*, **104**, No. 7, 451-454 (1957) July.

Kinetic studies on the oxidation of nickel using the vacuum microbalance method have been extended to 1050 C in order to determine the conditions and mechanisms of breakdown of the metal in oxidation. Below 900 C nickel oxidizes in the normal manner and the rate data fit in well with experimental rate relationship already established. At 900 C and higher, parabolic rate law plots of the data show increasing values of the constant with time. At 1000 C and higher, the oxide cracks away from the metal. It is suggested that nickel fails in protective oxidation due to a loss of adhesion at the oxide metal interface.

14291

3.8.4, 6.3.3, 3.5.9

Kinetics of the Oxidation of Chromium. EARL A. GULBRANSEN AND KENNETH F. ANDREWS. *J. Electrochem. Soc.*, **104**, No. 6, 334-338 (1957) June.

The oxidation of high purity chromium was studied over the temperature range 700-1100 C using the vacuum microbalance method. Below 900 C conventional oxidation curves were obtained which can be fitted to the parabolic rate law. Above 900 C and for a film thickness of approximately 4800 Å, the rate of oxidation increased in an unusual manner. This increase in the rate of oxidation disappeared on further oxidation. At temperatures of 1050 C and higher a large increase occurred in the

rate of oxidation, suggesting that the oxide film was no longer protective for film thicknesses greater than 42,000 Å.

A logarithmic plot of the parabolic rate law constant vs $1/T$ shows two straight lines separated by a transformation region. This gives 37,500 cal/mole and −15.3 entropy units for heat of activation and entropy of activation between 700 and 900 C and 59,400 cal/mole and −6.2 entropy units for 1000-1100 C.

The rate of evaporation and the rate of oxidation of chromium are equal at about 950 C. This corresponds to the transformation region between the two mechanisms of oxidation. It is concluded that the failure of chromium in oxidation is closely related to the high vapor pressure of chromium above 900 C.   14281

5.   PREVENTIVE MEASURES

5.2   Cathodic Protection

5.2.2, 8.9.3

Application of Zinc Anodes to Natural Gas Pipelines. *Gas Age,* 120, No. 2, 41-43 (1957) July 25.

Combination of a good pipe coating plus cathodic protection has proved to be both economical and successful to such an extent that current practice is to provide both a coating and cathodic protection on all new transmission pipelines. It is a relatively easy and inexpensive matter to apply cathodic protection to a coated pipeline as compared to a bare pipeline since current requirements are only a small fraction of that required for the bare pipeline. In the case of existing pipelines which are not coated it is sometimes desirable to use galvanic anodes to provide local "hot spot" protection in corrosive areas. Design intended for use on coated steel transmission pipelines is given. Protection of pipeline in soil, undersea pipeline and in special cases is described. Graph.—INCO.   15272

5.2.2

Zinc Anodes for Cathodic Protection. J. H. MORGAN. *Corrosion Technology,* 4, 272-274 (1957) Aug.

Cathodic protection afforded by sacrificial zinc anodes for iron and steel structures, galvanized cold water storage tanks, aluminum and lead cables and marine installations such as ship hulls; zinc anode design.—MR.   15376

5.2.3, 7.5.5, 3.2.2

Cathodic Protection of Brewery Liquor Tanks. A. W. HUBBARD. *Corrosion Prevention & Control,* 4, No. 10, 57-58 (1957) Oct.

Two cast iron liquor tanks showed widespread pitting and rust nodules on sides and bottom after 15 years' service. Paint systems and magnesium anode scheme were ruled out because of possibility of contamination. Solution was impressed current. 250-volt single phase 50-cycle supply was fed to small transformer/rectified which was arranged to serve protective graphite anodes in each tank via distribution box. Result was deposition of calcareous deposit (powdery and easily removed) and complete suppression of corrosion.—INCO. 14882

5.2.2

"We Use Single Anodes, Not Beds." J. EMERY. Rio Grande Valley Gas Co. *Gas Age,* 120, No. 3, 15-16 (1957) Aug. 8.

Rio Grande Valley Gas Co. has successfully used single distributed magnesium anodes for cathodic protection of 11 gas distribution systems since 1953

and prefers this method to installing beds of anodes in most cases. Primary reason for installing magnesium in this manner is not so much to get benefit of more drainage points and a more even flow of current to mains and services, but rather to avoid having to bond existing Dresser couplers in inaccessible locations. An accidental contact will cause loss of protection on only one section of pipe and search for contact or contacts can be confined to this relatively small section of pipe. A single anodes will protect varying amounts of coated pipe, depending principally upon: resistance of soil, resistance of coating, quality of insulating joints and size of pipe protected. Diagrams.—INCO.

14619

5.2.1, 4.5.3, 8.4.3

Cathodic Protection of Underground Refinery Equipment. P. W. SHERWOOD. *Corrosion Technology,* 4, No. 9, 313-317 (1957) Sept.

Cathodic protection, either alone or in combination with other protective measures, is useful for underground structures which suffer point or pit corrosion. Types of current source—rectified, generated on location, or provided by galvanic anodes are reviewed. Basic data required, field instruments used to obtain it and field survey techniques are discussed. Interference with other metal structures and its prevention is considered.—INCO.   15086

5.2.1, 4.5.3

Cathodic Protection. L. B. HOBGEN, K. A. SPENCER AND P. W. HESELGRAVE.

Positions Wanted

BSE (Electrical) University of Michigan '34 Twenty years products pipe line experience. Electrical, mechanical, structural design. Last ten years complete direction of design, installation, test, training, maintenance for successful cathodic protection system. Executive ability. Desire responsible position. CORROSION, Box 58 - 21.

Corrosion Engineer—Twelve years' continuous experience in all phases of corrosion work including pipe lines, tanks, well casings, marine equipment etc. BS degree general engineering, registered professional enginer, married, age 34. CORROSION, Box 58-22.

Positions Available

West Coast Corrosion Engineering Corporation, P. O. Box 1164, Santa Ana, California has opening for corrosion engineer with five years minimum experience performing pipeline design surveys for application of cathodic protection.

Large independent oil company Mid-Continent area has opening Pipeline Department for engineer with corrosion experience. Applicant must be graduate engineer and must have oil field experience with at least three years specialized corrosion work. CORROSION, Box 58-20.

Sales Engineer. Opportunity of a lifetime. Progressive top rated Eastern Paint Manufacturer has splendid opening for experienced corrosion prevention salesman. Prefer young man with ability to manage, supervise and train salesmen in his department. Future possibilities unlimited and depending on his ability. Replies treated in strict confidence. CORROSION, Box-58-24.

Proc. Inst. Elec. Engrs., **104**, Pt. A, 307-319 (1957) Aug.

Mechanisms of electrolytic corrosion. Practical methods of applying cathodic protection. Electrical survey of buried structures. Main applications of cathodic protection and the general economics affecting its use.—BTR.   14920

5.2.1
Contribution to the Theory of Cathodic Protection. Pt. II. CARL WAGNER. *J. Electrochem. Soc.*, **104**, 631-637 (1957) Oct.

Conditions are shown under which the differences in the local single electrode potential are sufficiently low so that complete cathodic protection without significant hydrogen evolution can be accomplished by using an automatic control of the impressed current.—BTR.   15150

5.2.2, 8.4.2
Zinc Bracelets Protect Undersea Line. D. M. TAYLOR. *Petroleum Engr.*, **29**, No. 11, D81- D82, D84, D86 (1957) Oct.

Tennessee Gas is spotting 1000 zinc anodes that fit around pipe like bracelets every mile on its new offshore Louisiana line. These "bracelets" fit flush with concrete coating and are designed to protect line for a minimum of 40 years. Advantages of circular zinc anodes include low maintenance—there are no test leads to be torn off, no buoys to maintain. Weight of joint of pipe containing anode is just about the same as rest of pipe because zinc weighs about the same as concrete. Installations are inexpensive, since cost of zinc runs less than 30 cents per lb. Zinc anode assemblies are rugged enough to withstand normal construction practices, anodes will not crush as they go over rollers

and they are not in line of blast of jet-ting machine. Photos, diagrams.—INCO.
15099

5.2.2, 7.2, 8.4.2
Application of Zinc Anodes to Gas Distribution Systems. *Gas Age*, 120, No. ?, 18-20, 22, 58 (1957) July.

Cathodic protection of coated steel, gas or other distribution piping of all welded construction can be easily accomplished if electrical insulation is provided between distribution piping and bare piping or electrical grounding wires. Zinc anodes are particularly well suited for use in applying cathodic protection to distribution systems in congested areas since by using them it is possible to minimize interference effects on other piping and cable systems. Also zinc anodes may be placed close to or underneath pipe which is to be protected so that a minimum amount of excavation work is necessary for their installation. Most difficult problem in applying cathodic protection to distribution sys-tems is that of insulating-off distribution system from other underground metal-lic structures which are not being placed under cathodic protection. Step by step procedure is given for application of cathodic protection to a distribution system in an urban area. Diagrams.—INCO.
15269

6. MATERIALS OF CONSTRUCTION

6.3 Non-ferrous Metals and Alloys——Heavy

6.3.10
Nickel, Including High-Nickel Alloys. R. M. FULLER. Inco. *Ind. and Eng. Chem.*, 49, No. 9, Pt. 2, 1618-1628 (1957) Sept.

Current annual review of published references relating to nickel and nickel alloys. Alloys containing 40 nickel or more or substantial quantities of cobalt comprise the materials considered. Review covers: Developments on sources

TITANIUM—available <u>now</u> for long service

of supply, mining, refining, melting and casting; research and development in physical metallurgy including physical properties, structure, thermal properties, sorption, electrical and magnetic properties, diffusion, corrosion and radiation effects; welding and fabrication; high temperature materials including corrosion and oxidation behavior, physical and mechanical properties, and applications; and developments in application of nickel and its alloys with particular reference to chemical and process industries (bromine, caustic, fluorine, sulfuric acid, sea and salt water, pulp and paper, petroleum) as well as electronic, nuclear and other applications. J. J. Moran, Jr. prepared section on high temperature applications and A. O. Barry and H. C. Waugh review fabrication and welding, respectively. 241 references.—INCO.

14951

6.3.10, 4.2.1, 3.5.8, 3.5.9

Temperature and Stress Dependence of the Atmosphere Effect on Niochrome V. P. SHAHINIAN AND M. R. ACHTER. U. S. Naval Research Laboratory, October, 1957, 17 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131339.)

The general features of the atmosphere effect on Nichrome V, a nickel-chromium alloy, were found to be similar to those of nickel with one exception: the points of reversal in strength of vacuum and air specimens are displaced to longer times in accord with the greater oxidation resistance of the alloy. Creep rupture tests were performed on the alloy in vacuum and in air at 1100, 1300, 1500, 1700 and 1900 F. Nichrome V, a material with higher oxidation resistance than nickel, was used to observe the influence of oxidation characteristics on the atmosphere effect. The tentative mechanism involving two competing processes which was used to explain the reversals in nickel was also applied to Nichrome V.—OTS. 15085

6.3.10, 6.2.5

Study of Austenitic Corrosion-Resistant Cast Nickel-Molybdenum Alloys. W. GODECKE. *Werkstoffe u. Korrosion,* **8,** 580-587 (1957) October.

Report of electrochemical and metallographic investigation of Hastelloy B and Hastelloy C type alloys. Comparison was made with properties of austenitic nickel-chromium steels. Current density-potential curves for Hastelloy B, Hastelloy C and stainless steel and nickel-molybdenum phase diagram are given. Effects of heat-treatment and carbon content on structure, constitution and mechanical properties and effect of mechanical working on hardness are included.—INCO. 15280

6.3.11, 4.3.2

Gold Alloys as Process-Solution-Lubricated Sleeve Bearings. P. B. McCARTHY. General Electric Co. U. S. Atomic Energy Commission Pubn., HW-35550 (Del.) March 1, 1955, (Declassified with Deletions Feb. 25, 1957), 17 pp. Available from Office of Technical Services, Washington, D. C.

Ten materials in which gold was alloyed with copper, silver, graphite, platinum, nickel or zinc were evaluated in this study. Corrosion tests to determine the resistance of the alloys to boiling 60 to 65% nitric acid showed that with the exception of an alloy containing 51 w/o gold and 49 w/o graphite which dissolved in 48 hr and an alloy

containing 90 w/o gold and 10 w/o graphite which lost 2.3 w/o in 240 hr the alloys were essentially corrosion resistant. (auth.)—NSA. 15337

6.3.15, 3.2.2, 4.3.2

Corrosion Keys—Titanium (Commercially Pure.) D. L. MACLEARY. du Pont. *Chem. Processing,* **20,** No. 7, 67, 69, 71, 73 (1957) July.

Data given are applicable to unalloyed, commercially pure grades of titanium. Information that cannot be incorporated into Corrosion Keys, but equally important to corrosion engineers and equipment designers, concerns fact that chloride solutions do not produce stress corrosion cracking in titanium. Red fuming nitric acid containing less than 1.5% water is the only known chemical that will produce stress corrosion cracking. Titanium also resists pitting, galvanic and cavitation attack. When coupled to dissimilar metals in sea water tests, position of titanium (passive) in galvanic series is with the passive 18-8 stainless steels and passive Inconel.—INCO. 15017

6.3.6, 8.9.5

Aluminum Bronzes for Marine Applications. W. L. WILLIAMS. Naval Eng. Exper. Station. *J. Am. Soc. Naval Engrs.,* **69,** No. 3, 453-461 (1957) August.

Early history of use of aluminum bronzes for marine applications is reviewed. Chemical compositions and mechanical properties required by MIL-B-15939 (wrought) and MIL-B-16033 (cast) are discussed and shown in tables. These include data for nickel-containing aluminum bronzes. Corrosion properties are discussed with reference to velocity effects, pitting, crevice attack, dealumization, impingement, galvanic attack, effects of welding, stress corrosion and fouling. Special attention is given to fatigue and corrosion properties (data tabulated). Magnetic properties are considered. Specific applications discussed are salt water piping, condenser components, and propellers. Cupro-nickel alloys are mentioned for comparison.—INCO. 15145

6.3.4, 4.3.2, 4.3.3, 3.5.9

Corrosion Resistance of Cobalt. R. S. YOUNG. Inco of Canada. *Corrosion Technology,* **4,** No. 11, 396-397, 403 (1957) Nov.

Early research and literature on cobalt corrosion are reviewed. Results are discussed of study of behavior of cobalt in dilute acetic acid, ammonia, and sulfuric acid solution, with and without prior heating to 300-900 C in air and nitrogen. Without heating, corrosion rate was roughly of same order as that of nickel, though attack of cobalt in sulfuric acid was higher. Both heated and unheated samples showed lowest corrosion in ammonia solutions, due to formation of adherent, dark film. Heating samples in air at 300 and 500 C gave same results as unheated samples with acetic acid, while 700 and 900 C have increasing corrosion. Heating in nitrogen at all temperatures gave roughly equivalent corrosion, higher than unheated specimens, with acetic acid. With sulfuric acid, samples heated in air at 300 and 500 C, and in nitrogen at 900 C, showed lower corrosion rates than unheated specimens, while all other samples showed approximately same attack as unheated specimens. Corrosion rates are tabulated.—INCO. 15182

6.4 Non-ferrous Metals and Alloys—Light

6.4.2

High-Strength Aluminum Casting Alloy 40-E: D.T.D. 5008: Latest Developments and Foundry Experience. J. F. GARDNER AND M. R. HINCHCLIFFE. *Metallurgia,* **55,** No. 328, 79-84 (1957).

40-E is an aluminum-zinc-magnesium-chromium-titanium alloy used in the room-temperature aged condition. It combines relatively high strength with excellent machinability, good corrosion-resistance and weldability. Recommendations are made for the founding of this alloy. The increasing use of 40-E to replace heat-treated alloys is illustrated by recent applications.—MA. 14916

6.4.2

Aluminum Alloys. R. L. HORST. *Ind. & Eng. Chem.,* **49,** No. 9, Pt. II., 1578-1583 (1957) Sept.

The author reviews the use of aluminum alloys as a material of construction especially for architectural applications and in the chemical process industry. The use of aluminum in atomic energy equipment is discussed. The effect of the following chemicals on aluminum is discussed: Aliphatic acids, ammonia, ammonium nitrate, cadmium sulphate, chlorine, coal, fertilizers, mixed acids, naphthenic acid, naval stores, nitric acid, oxygen, tall oil, transportation of chemicals, vinyl acetate and water. The use of aluminum in the food industry, marine industry, packaging industry, petroleum industry, paper industry and power industry is reviewed. A bibliography of the reference used is given.—ALL. 14909

6.4.2

SAP: A Sintered Aluminium Material of High Hot-Strength. R. IRMANN. *Aluminium,* **33,** No. 4, 250-259 (1957).

SAP is a proprietary sintered aluminum powder with controlled oxide content. It does not recrystallize; electrical, mechanical and thermal properties are given. Its anti-corrosive properties are about the same as for pure aluminum; its resistance at ~400 C is particularly good. Notes on its working and welding are given and alloys, including one with silicon are mentioned and their uses noted.—MA. 14963

6.4.2, 3.7.2, 3.7.3

Researches into Aluminum-Magnesium-Base Foundry Alloys. M. KATO AND Y. NAKAMURA. *Aluminium,* **33,** No. 3, 152-162 (1957).

Kato and Nakamura studied the properties and casting of aluminum-5 and 10% magnesium alloys. The properties were adversely affected by impurities and by unsuitable melting, casting and heat-treatment techniques. Silicon and iron are particularly injurious, both as regards mechanical properties and corrosion-resistance, but manganese is favorable. Low pouring temperatures, plentiful use of risers and the addition of fluoborate to the molding sand and of beryllium to the alloy are recommended. 12 references.—MA. 14950

6.4.2, 8.4.5

Aluminium as a Construction Material for Reactors. (In German.) J. STAEHELIN. *Metall,* **11,** No. 9, 746-752 (1957) Sept.

The various properties of aluminum which motivate its widely accepted use

in thermal reactors are discussed. The survey extends over metallurgical properties affecting the process of alloying aluminum with uranium, thermal properties and corrosion, both of importance in cooling systems, the behavior of the metal under irradiation, creep resistance and, finally, induced radioactivity.—ALL.
15059

6.4.2, 3.7.2, 4.6.2

Corrosion Resistance of 2S Aluminium in High Temperature Water as Related to the Ratio of Its Iron and Silicon Content. YOSHITSUGU MISHIMA. *Light Metals*, No. 25, 51-57 (1957) July.

In order to determine the optimum ratio of the iron and silicon content in commercial 2S aluminum to be used for reactor applications, corrosion test has been carried out in distilled water kept at high temperatures between 120 and 300 C in steel autoclave. Pyrex glass reservoir with pyrex lid was used to prevent water from being contaminated by iron ion coming from steel. The glass reservoir contains specimens hanging one by one by cotton string without coming into contact with each other. At the higher temperatures where the string can no longer resist the attack of water, specimens were heated with photographic dry plate glass pieces between them. Weight change of the specimen was measured. It is clearly seen that 2S aluminum containing from four times or so as much silicon has better corrosion resistance in high temperature distilled water. Cold-rolled sheet has slightly better resistance to corrosion than an annealed one and grain size seems to play a role. 52S aluminum alloy, contrary to the conclusion in foreign literature, is found to be fairly corrosion resistant in high temperature water. (auth.)—ALL.
14995

7. EQUIPMENT

7.8 Wires and Cables (non-electrical)

7.8

Relation Between the Corrosion of Mining Cables and Methods of Their Manufacture. (In Czech.) EMIL HILA AND JOSEF TEINDL. *Hutnik*, **7**, 158-161 (1957) May.

Corrosion of mining cables from the point of view of melting practice, structure, grain size, components, method of drawing, quality of surface of material, martensite formation, quality of lubrication, patenting and effect of hydrogen.—BTR.
14702

7.8

Corrosion of Steel Wire Ropes and Its Prevention. F. PODBREZNIK. *Zastita Materijala*, **5**, No. 2, 58-62 (1957).

The article describes corrosive damage to steel wire ropes and discusses its causes and possibilities of protection. The tests for protection by cold phosphatization are especially stressed. Finally the possibilities of corrosion of steel wire ropes by contact with other materials, especially wood, are mentioned.—RPI.
14340

7.8, 5.9.2, 5.3.4

Spring Design XXXI. W. R. BERRY. *Mechanical World*, **137**, No. 3460, 514-520 (1957) November.

At the end of the last article of a long series on the design of springs, the author considers the protection of the steel wire used. With plated wire it is said to be impossible to get rid of the hydrogen embrittlement caused by acid pickling in hardened and tempered steel,

but patented galvanized wire has given satisfactory service up to 0.212-in. diameter. The author admits that zinc coated wire may accelerate sludging when used in oil baths, but sees no necessity for wire used in this way to be coated at all.—ZDA.
15235

8. INDUSTRIES

8.4 Group 4

8.4.2, 4.4.7

Contributions to the Study of Internal Corrosion. J. MORLET AND C. GEOFFRAY. *Gas J.*, **291**, 332-334 (1957) Aug. 14. Corrosion of steel mains and pipes by synthetic gases, made up from nitrogen, carbon dioxide and oxygen, with or without water, compared with town gas, under different pressures. Suggested control, including limiting oxygen content and dehydration.—MR.
14822

8.4.5

Corrosion of Metals and Alloys in SIR and STR Process Streams. R. H. PERKINS AND C. M. SLANSKY. American Cyanamid Co. U. S. Atomic Energy Commission Pubn., IDO-14035, March 1952 (Declassified Feb. 23, 1957), 148 pp. Available from Office of Technical Services, Washington 25, D. C.

The available classified and unclassified literature is reviewed relative to the corrosion of metals and alloys in solutions similar to SIR and STR fuel-recovery process streams. Illium R, Carpenter 20, and Hastelloy F are the likely materials of construction for the SIR dissolver while Type 347 or 304 E.L.C. stainless steel is suitable for handling process streams following the

dissolver. Corrosion in the STR dissolver is largely dependent on the presence or absence of an oxidizing agent. In the absence of a strong oxidizing agent, the dissolver can be made of Monel, silver, or Hastelloy F. for temperatures up to boiling. Platinum was the only metal reported that was resistant to mixtures of hydrofluoric acid and strong oxidizing agents. The processing equipment following the STR dissolver can be made of either Type 347 or 304 E.L.C. stainless steel. (auth).—NSA.
15393

8.4.5

Sodium Graphite Reactor Quarterly Progress Report for September-November 1953. G. M. INMAN, ed. North American Aviation, Inc. U. S. Atomic Energy Comm. Pubn., NAA-SR-956, July 1, 1954 (Declassified March 2, 1957), 105 pp. Available from Office of Technical Services, Washington, D. C.

Two sodium-graphite central station power plant designs were investigated. The first design is for an enriched uranium converter of 150 Mw, and the second is a thorium thermal breeder of 300-Mw capacity. Engineering studies related to the general design of sodium-graphite reactors are reported. Metal moderator and coolant temperature coefficients of reactivity were evaluated for slow, fast, and very fast runaways in sodium-graphite reactors. The reactor is stable except at room temperature. Calculations for a startup accident in a 30-Mw SGR were carried out, the results of which emphasize the importance of full-power coolant flow rates during the startup process. By using the fact that the uranium β phase does not exist in a uranium-zirconium alloy containing 20 at % zirconium, it is

shown that substantial reduction in power cost per kwh may be achieved by operating the reactor at high power. Neutron age was calculated for a number of hydrocarbons which show promise for use as moderators. Tensile tests and welding properties of the projected zirconium cans for the graphite moderator sections are reported. Strength

tests were completed for flash-welded joints of zirconium-347 stainless steel tubing. The joints are mechanically feasible for reactor use and favorable corrosion results were obtained from static sodium studies. Dynamic corrosion data are required. Weldability studies are reported for nickel, 304 L stainless steel and a series of typical core tank joints. The design of a forced-convection loop for dynamic sodium-zirconium corrosion studies is described. A remote welding device was designed for the repair of coolant tubes. The dimensional stability of uranium and uranium alloys subjected to thermal cycling and quenching tests was studied in the α and high β regions. The unfavorable characteristics of the β phase transformation were noted and it is suggested that under the reactor operating conditions, where the surface of the fuel slug is adequately cooled, a sufficient shell of α material might be maintained around an inner β phase to contain the dimensional instability. Nondestructive testing of fuel element components at high temperatures is proceeding with an evaluation of techniques using eddy currents, temperature-sensitive paints and infrared photograhpy. A study of the production of thermal energy in an iron thermal shield by capture processes has been extended to include the effect of fast-neutron leakage. The results are graphically presented for several shield thicknesses. The physical properties of several hydrocarbons were investigated in order to determine their suitability as biological shield coolants. Kerosene and toluene seem particularly promising.—NSA.   **14968**

8.4.5

Proposal for Dynamic In-Pile Corrosion Tests at MTR. E. S. Lembersky and Warren Witzig. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-CP-156, Dec. 8, 1953 (Declassified March 5, 1957), 23 pp. Available from Office of Technical Services, Washington, D. C.

Loop design for simultaneous study of corrosion and radiation effects on fuel elements is proposed. The value of such experiment is discussed and the expected contamination problems analyzed.—NSA.   **14976**

8.4.5

The Chemical Processing of Two-Region Aqueous Homogeneous Reactors. D. E. Ferguson. Oak Ridge Nat'l. Lab. *Nuclear Science & Eng.*, **2**, No. 5, 664-675 (1957) Sept.

Promising scheme for chemical processing of thorium breeder reactor consists of following operations: concentration of insoluble fission and corrosion products (ferric oxide, chromic oxide and zirconium dioxide) from core system into small volume of fuel solution, combining slurry with irradiated thorium oxide slurry taken from blanket, recovery of deuterium oxide by evaporation, dissolution of thorium and uranium in nitric acid and recovery of uranium and thorium by solvent extraction. Use of hydrocyclone and underflow container for concentrating insoluble fission and corrosion products under simulated reactor conditions was demonstrated on dynamic loops. In laboratory tests of uranium peroxide precipitation, it was shown that 99.9% of uranium could be recovered with separation factor of greater than 10 from nickel, rare earths and alkali metals. Flow sheets.—INCO.   **14884**

8.4.5

The Metallurgical Problems of Nuclear Reactors. F. Giordani. *Metallurgia Italiana*, **49**, No. 1, 1-13 (1957).

A review covering the use of metals in nuclear-energy plants as fuels, heat-exchange media and constructional materials. The processes of nuclear fission and breeding are explained.—MA. **14908**

8.4.5

The Effects of Irradiation Cycling on Pressurized Water Reactor Blanket Fuel Elements. John D. Eichenberg. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-167, March 13, 1957, 37 pp. Available from Office of Technical Services, Washington, D. C.

Two PWR blanket fuel rods were irradiated in the L-42 cycling loop at the MTR at a maximum heat flux of 484,000 Btu/hr-ft.[2] One of the rods had a 0.005-in. diam defect; the other was undefected. The rods were power cycled 533 times and achieved a maximum burnup of 1260 MWD/T. No changes in appearance or dimensions occurred as a result of the irradiation. No increase in the hydrogen content of the Zircaloy-2 cladding over that expected from the corrosion process was noted. Center melting occurred in the uranium dioxide from the defected specimen, whereas neither melting nor grain growth occurred in the uranium dioxide from the undefected specimen which was irradiated under essentially the same neutron flux. Two mechanisms are postulated which help to explain the observed phenomenon. The poorer thermal conductivity of the steam atmosphere in the defected rod as compared with the helium atmosphere in the undefected rod, coupled with the circumferential cracking in the defected rod, would explain a portion of the higher temperature. In addition, the formation of uranium oxide with an oxygen/uranium ratio of 2.18 to 2.25 and with a possible lower melting point is shown to be thermodynamically possible. This would also help explain the observed difference. However, the pos-

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sibility of some unknown mechanism producing part of the observed difference in behavior cannot be discounted. (auth).—NSA.   14960

8.4.5
PAR Homogeneous Unit Gains; Corrosion Seems Licked. J. E. KENTON. *Nucleonics*, **15**, No. 9, 166-168, 170, 172, 174, 176, 178, 180-182, 184 (1957) Sept.

Discussion of development of Pennsylvania Advanced Reactor. Research and development program now being carried out covers slurry-handling, components, systems and maintenance. Four 200 gpm loops used in corrosion testing showed that erosion rates are not constant but level off. Erosion rates, which vary with material and concentration are very reasonable and are not too much greater than that of water on carbon steel (1-2 mils/yr.). After the first 600-700 hours, incremental attack drops off to only $\frac{1}{4}$ mil/yr. This is attributed to the fact that slurry particles break down under pumping action to ultimately < 1 micron and become spherical instead of jagged and abrasive. Once they have broken down, erosion-corrosion rate slows down. Loop D, a half-scale mockup of 1 primary coolant circuit is made of 10-in. 304 stainless steel with 347 stainless flanges. Diagrams.—INCO.
    14941

8.4.5
Corrosion and Stability Tests on Chemical Poisons in High-Temperature Water. C. R. BREDEN AND ALMA ABERS. Argonne National Lab. U. S. Atomic Energy Commission Pubn., ANL-5147 (Ref.), Sept. 1, 1953 (Declassified March 20, 1957), 48 pp. Available from Office of Technical Services, Washington, D. C.

Corrosion-stability tests have been made in static autoclaves at 500 and 600 F on solutions of compounds having high neutron cross sections to evaluate their usefulness for shutdown purposes. The only compound tested which appeared to be completely stable in 600 F water was H_3BO_4. Limited corrosion data did not show it to cause excessive corrosion of zirconium or stainless steel. (auth.)—NSA.   14946

8.4.5, 3.4.3, 6.2.5
S3G Corrosion Product Activity Buildup with a Stainless Steel Unit Cell. J. W. SAPP. Knolls Atomic Power Lab. U. S. Atomic Energy Commission Pubn., KAPL-M-SMS-81, September 30, 1957, 33 pp. Available from Office of Technical Services, Washington, D. C.

In order to develop an improved reactor core for use in S3G/S4G utilizing steel fuel elements, Knolls Atomic Power Lab. has proposed that a unit cell made up of improved stainless steel fuel elements be inserted and tested in S3G Core 1. Since the insertion of this unit cell in S3G core 1 will effectively double the area of the stainless steel exposed to the coolant in the high neutron flux region, it is necessary to calculate the effects of this additional stainless steel on the buildup of long-lived corrosion product activities in the main coolant system. In addition, it is necessary to analyze the effects of stainless steel on corrosion product activity buildup so that proper measurements and samples be taken in S3G Core 1 with the SS unit cell such that the effects of an all stainless steel core in S3G/S4G on plant accessibility and coolant purification can be properly assessed. (auth.)—NSA.   15415